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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

# WARTIME REPORT

ORIGINALLY ISSUED
October 1945 as
Memorandum Report A5J19a

## A FLIGHT INVESTIGATION OF THE ICE-PREVENTION REQUIREMENTS OF THE UNITED STATES NAVAL K-TYPE AIRSHIP

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NACA

WASHINGTON

MR No. A5J19a

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MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

# A FLIGHT INVESTIGATION OF THE ICE-PREVENTION REQUIREMENTS OF THE UNITED STATES NAVAL K-TYPE AIRSHIP

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## SUMMARY

This report describes the first phase of a comprehensive research program designed to investigate ice prevention and elimination on airships for the purpose of developing suitable airship ice-prevention equipment.

A Naval K-type airship was outfitted with photographic and meteorological equipment to determine the extent and effect of ice formations on the airship during icing conditions. The propellers were equipped with electrically heated blade shoes.

A description of the equipment is presented together with records taken during a condition of wet snow and freezing rain in which the airship was flown successfully for $2\frac{1}{2}$ hours.

## INTRODUCTION

During the season when icing conditions occur in the northern latitudes, it has been necessary to restrict operation

of airships to regions relatively free from ice on the occasions when such conditions are known to exist. These operational restrictions are necessary as it is known that, when flying in certain types of icing conditions, the formation of ice can endanger the airship or interfere with its operation in several ways: (1) extensive accumulations on the envelope may overload the airship or throw it out of trim, (2) carburetor ice may cause engine failure, (3) ice may be thrown from the propeller blades causing damage to the envelope and car, (4) ice on the windows may obstruct the pilot's vision, and (5) various major and minor controls may become stiff or possibly inoperative.

In order to determine the extent of ice-prevention equipment required to operate airships with safety during icing conditions, it was necessary first to define certain of the problems of ice formation which are unique to the airship in flight. In some cases, where similarity exists, techniques developed to prevent ice on the airplane are applicable to the airship. For example, use of an adequate amount of carburetor-air preheat in the present service installations has largely eliminated the problem of carburetor icing on airships. Propeller and windshield icing problems likewise may be solved by applying techniques developed for heavier-than-air craft.

In order to determine the effectiveness of the application of these techniques and to define the problems such as envelope

and control icing which are unique to the airship, a comprehensive research program has been undertaken by the Ames Aeronautical Laboratory. The ultimate objective of the program is the devclopment of ice-prevention equipment to provide adequate protection for the airship during icing conditions.

The present phase of the research program was undertaken to define the problems which are unique in the prevention of ice formation on airships, and was carried out at the Naval Air Station, Lakehurst, New Jersey, on a U.S. Naval K-type airship equipped to photograph ice formations and to record meteorological conditions. Ice-prevention equipment installed on the airship included carburetor-air preheat, electrically heated propeller blade shoes, and a rudimentary heated-air system for the windshield. The preparation and operation of the airship for this investigation was carried out, and all photographs taken, by personnel of the Naval Air Station, Lakehurst, New Jersey.

## DESCRIPTION OF EQUIPMENT

### The Airship

The airship on which the tests were made is of the type currently employed by the Navy for patrol and convoy work. Designated as the K-24 it is 252 feet long, has a volume of 435,000 cubic feet, and a gross lift of 26,970 pounds when employing helium gas. A complete description appears in

references 1 and 2. As equipped for this project, the K-24 airship is shown in figure 1.

## Photographic Equipment

Scanning various parts of the car, envelope, and fins were twelve 16-millimeter electrically heated gun-sight cameras arranged to obtain photographic evidence of ice formation. The camera assembly and details are shown in figures 2 and 3. The camera locations are shown in figures 4 and 5. The areas scanned by the cameras were painted black to provide a contrasting background for ice. All 12 cameras were operated simultaneously from the instrument panel in the car. (See fig. 6.)

## Propeller Ice-Prevention Equipment

Electrically heated propeller blade shoes were installed on both propellers as shown in figure 7. Power at 28 volts direct current was delivered to the shoes through the brush and slip-ring contacts shown in figures 8 and 9. Spinners attached to the propeller hubs afforded protection for these contacts by shielding them from ice and snow accumulations.

Provision was made to energize the blade shoes on each propeller alternately or both simultaneously. Voltmeters and ammeters on the instrument panel indicated the power to the propeller blade shoes and a thermocouple mounted between the shoe and the leading edge of one blade on each propeller indicated the temperature rise of the blade.

The thermocouple junction on the starboard propeller was located 33 inches from the center line, while the thermocouple

on the port propeller was located 21 inches from the center line of the hub.

In addition to the propeller equipment, a protective strip consisting of several layers of heavy fabric was attached to the envelope and car in the plane of the propellers to impede penetration of ice particles in the event of incomplete protection by the propeller ice-prevention system.

## Meteorological Equipment

In addition to the standard flight instruments, an aerograph and an electrical humidity indicator were installed as shown in figures 10, 11, and 12. The aerograph is a recording instrument which provides a record of altitude, temperature, and humidity during flight. The humidity indicator, together with a thermometer exposed to the air stream and an altimeter, provided an instantaneous indication of the same quantities.

## Windshield Ice-Prevention Equipment

Flexible ducts were led from a 20,000-Btu-per-hour combustion heater to the forward windshield to form a rudimentary ice-prevention system. The ducts terminated in fantails and could be directed at any part of the windshield.

## Miscellaneous Equipment

The relative temperatures of the envelope, helium, and air were measured with a total of six iron-constantan thermocouples installed at the forward and aft ends of the envelope. The two installations were identical: a thermocouple 3 inches above the surface in the air stream, one on the fabric surface and another

in the helium 6 inches from the surface.

## FLIGHT TEST DATA

The following description of an icing flight made by the K-24 airship includes both meteorological and photographic observations to define the icing conditions and the extent of the ice formations on the airship.

### Meteorological Conditions Concurrent with Icing Flight

On the morning of the flight two low-pressure centers, one from the Great Lakes region and the other from West Virginia, merged over New Jersey and moved out over the Atlantic ocean. At the same time snow showers were reported in the mountains between West Virginia and Maine. The radiosonde, from which the record in figure 13 was obtained, was released at Lakehurst at 11:00 a.m. (Eastern War Time is used throughout this report) and shortly thereafter snow and freezing rain began falling at Lakehurst. The weather map in figure 14 shows that in the region behind the low a mass of moist polar maritime air was overriding a colder mass of dry polar continental air. As the flow behind the low-pressure center became more northerly the temperature of the air aloft dropped very rapidly. By noon a layer of air having temperatures well below freezing ranged from 1700 to 4500 feet.

When the K-24 airship took off at 1:45 p.m. the conditions described above were at their maximum intensity with large

snowflakes falling, indicating rapid freezing aloft.

Moderate snowfall and freezing rain limited to the region of New Jersey, which was at the edge of the precipitation area, continued until about 6:00 p.m., at which time the snow changed to light rain. The precipitation stopped at about 7:30 p.m.

## Take-off Conditions

Prior to take-off the airship was fueled to 690 gallons of gasoline (400 gal disposable). The airship left the hangar in equilibrium with 700 pounds of sand ballast and a crew of eight.

The following weather observations were made: mixed heavy snow and sleet, light fog, ceiling 400 feet, lower broken clouds, overcast estimated at 1300 feet, visibility three-quarters mile, temperature 35° F, dew point 34° F, relative humidity 95 percent, and surface wind NNE 8 miles per hour.

During the few minutes the airship was on the field before take-off, the upper surface of the envelope and horizontal fins were blanketed with a layer of wet snow. This layer of snow caused the airship to be tailheavy on take-off.

## Flight Data

Aerograph records and precipitation observations made on the airship during the flight are shown in figure 15.

The following photographs appear chronologically as they were taken on the flight. The groups of pictures showing the envelope, front of car, and fins were selected from 32 runs to show significant changes in the appearance of the accumulations of ice and snow.

An idea of the extent of the snow accumulated on various parts of the airship while on the ground and during the first 5 minutes of flight may be obtained from figure 16. The camera numbers correspond to those appearing in figures 4 and 5. Of the 12 cameras the records of cameras 3 and 7 are omitted. Camera 3 failed to operate properly and camera 7 showed no ice or snow to accumulate on the port helium valve at any time during the flight. At 1:50 p.m., when figure 16 was taken, heavy snow was falling and the propeller blade shoes were operating. Shortly after 2:00 p.m. the airship reached pressure height at 2000 feet.

The forward windshield was clear of ice upon take-off but the accumulation shown in figure 17, taken at 2:05 p.m., gradually became thicker and more extensive as the flight progressed. The ends of the heated-air ducts directed at the inner surface of the windshield may be seen in the lower half of the figure.

Figure 18 taken at approximately the same time shows ice accumulating on the leading edge of the oil-cooler air scoop, outrigger, and propeller spinner. At this time the airship was flying with the aft ballonet empty and 8° down-elevator

at an airspeed of 55 knots. This airspeed was maintained throughout the flight. Visibility was zero and heavy snow and rain were falling. The aerograph had collected a thin coat of glaze ice.

The snow accumulated on the top of the envelope and fins while on the ground is shown in figure 19, taken at 2:32 p. m., to be gradually thinning out. In the regions scanned by cameras 1, 8, 9, and 12 at the stern, car, and bow, snow and ice were building up slowly.

Figure 20, taken an hour after take-off, shows a continuation in the trends shown in the previous set of photographs taken 13 minutes earlier. The airship flew into a rain shower after these photographs were taken and the condition of the airship a minute later is shown in figure 21. The effect of the rain is most apparent in the records of cameras 2, 4, 10, and 11.

At 3:01 p. m. the amount of ice on the engine outriggers, shown in figure 22, is about the same as it was an hour before. (See fig. 18.) The airship was flying at 55 knots airspeed with 10° down-elevator, 2° up-inclination, and aft ballonet empty.

At about 3:10 p. m. (fig. 23 - cameras 2, 6, 8, and 9) ice started forming at a more rapid rate on the control and brace wires at the tail, on the fin leading edge, and on the car window. Thirty minutes later ice and impacted snow have continued to build up as

shown in figure 24. Very little snow remained on the envelope except at the bow and stern. The haze over a portion of the record of camera 12 is ice in the opening of the camera fairing. After 700 pounds of sand were jettisoned the airship was flying with $5^{\circ}$ down-elevator and $2^{\circ}$ up-inclination. Views of ice on the engine outrigger, spotlight, aerograph, and open airscoop are shown in figures 25, 26, 27, and 28.

At 4:05 p.m. 200 gallons of gasoline were jettisoned preparatory for landing. The airship landed at 4:10 p.m., about 200 pounds light. The camera records shown in figure 29 were made upon entering the hangar. The heavy accumulation of snow and ice shown on the stern by camera 1 persisted throughout the flight. The records of the cameras scanning other parts of the envelope show most of the snow to have melted or blown off.

No ice could be seen on the control wires between the rear of the car and the lower vertical fin, nor on the leading edge of the fin itself at any time during the flight. At no time were the controls sluggish or stiff and the airship remained under complete control throughout the entire flight.

The thermocouples mounted at the top of the envelope indicated near-freezing temperatures in the air, gas, and surface throughout the flight. Accurate measurements could not be made of these temperatures or propeller-blade temperatures because of potentiometer vibration. Subsequent measurements were made successfully in nonicing conditions with the

potentiometer mounted in a bungee support.

## Landing Conditions

The weather conditions on landing were ceiling 400 feet, overcast, 1-mile visibility, light snow and fog, temperature 34° F, dew point 33° F, relative humidity 95 percent, and surface wind NNE 9 miles per hour.

Total precipitation during the flight was about 2½ inches of wet snow or 0.29 inch of water (equivalent).

The following pictures were taken while the K-24 was being docked. Figure 30 shows the thickness of the ice which had accumulated on the oil-cooler strut. The ice remaining on the car windshield, spotlight, and electric humidity transmitter can be seen in figure 31. Figures 32, 33, and 34 show the snow remaining on the bow and stern of the envelope and on the upper fin brace wires. Figure 35 shows the general clear appearance of the envelope immediately after landing.

## Heating Characteristics of Propeller Blade Shoes

Subsequent to the icing flight, ground and flight tests were made to determine the characteristics of the blade shoes on the fixed-pitch propellers. The current and power characteristics of the three blade shoes, connected in parallel, on each propeller are shown in figure 36. These values may be divided by three to obtain the characteristics of the individual blade shoes.

Typical transient heating curves of the propellers for flight and ground conditions, when operating the blade shoes at 28 volts, are shown in figure 37. These curves are furnished to indicate the time required to reach equilibrium rather than to provide an exact temperature calibration. While the propeller temperatures are fairly insensitive to speed in the normal operating range in straight flight, during sustained turns the temperature of the propeller on the outside may drop 10° to 20° F, indicating the desirability of maintaining a straight flight path during icing conditions to obtain maximum protection.

## DISCUSSION

In accordance with the objectives of the present research, the data presented herein establish the nature of the ice-prevention equipment required by a K-type airship in flying through a mixture of heavy wet snow and freezing rain at temperatures ranging from 30° to 34° F. Until further data are accumulated in icing conditions, these data are considered applicable only to the conditions of the present tests.

It is notable that airships have flown for extended periods of time in dry snow without adverse effect. While it may be concluded from such experiences that dry snow does not present an icing problem in flight, it does not necessarily follow that an airship may be flown with equal success

in wet snow since wet snow has far greater adhesive qualities.

The series of photographs of the envelope and fins starting with figure 16 show, however, that as soon as the airship attained cruising speed the wet snow began to blow and melt off, even though the airship was flying almost continually in snow during the entire flight. The only notable exceptions to this tendency on the envelope were the regions at the stern and bow scanned by cameras 1 and 12, respectively. Even though the snow which had accumulated in these regions before take-off continued to build up throughout the flight, the airship did not become difficult to control at any time.

If, in estimating the weight of the snow at the stern of the envelope, it is assumed that the density of the accumulation is one-third that of water and that it averages 2 inches in thickness, its weight would be about 500 pounds. Only when flying at very low altitude would such a load present a hazard to the airship. If, under this condition, the snow were to slide off, a rapid change in elevator angle would be required to compensate for the change in trim without loss of altitude. While the second largest accumulation of snow occurred on the bow of the envelope, it was not extensive enough to have any noticeable effect on the airship.

The accumulation of snow and ice on the engine outriggers, fin leading edges, and similar locations are not considered serious since they neither interfere with the operation of the airship nor add appreciably to its weight.

Thus it is concluded that an airship may be flown during conditions similar to those described herein without danger of becoming excessively heavy, and while ice-prevention equipment is desirable in the region of the envelope stern and bow, such equipment is not essential for the successful operation of the airship.

The amount of ice accumulated on the windshield in flight indicates the desirability of an adequate windshield ice-prevention system. The system installed for the reported tests was of very limited effectiveness.

As discussed previously, one of the greatest dangers to the airship is the ice thrown from the propellers into the car and envelope. The electrically heated propeller blade shoes provided adequate protection during the present tests since no ice was thrown against the car or envelope.

Likewise there was no evidence of ice in the carburetor-air-induction system, thus indicating the adequacy of the carburetor-air preheat system.

It is interesting to note that in contrast to the relatively clean condition of the K-24 airship upon landing after a 2½-hour flight, an airship moored at the mast during the same period of time accumulated an extremely heavy snow load on the fins and envelope. The snow, instead of blowing off as it did in flight, continued to build up as long as snow was falling. The comparative status of the two airships indicated that the flight and ground problems are appreciably different even under

identical weather conditions.

## CONCLUSIONS

The following conclusions are drawn from the data presented herein:

1. The extent of ice-prevention equipment required for the operation of an airship in conditions of mixed wet snow and freezing rain has been established. An airship may be flown successfully under these conditions when only the propellers and induction systems are adequately protected.

2. The propeller thermal-electric blade shoes when dissipating 1000 watts per blade were successful in preventing the formation of ice on the propellers under the conditions of the reported icing flight.

3. The installation of an adequate windshield ice-prevention system is very desirable.

4. While ice and snow accumulate at the bow and stern of the envelope during flight, the present tests indicate that ice-prevention equipment is desirable but not essential in these regions when flying in wet snow.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif., October 19, 1945.

# REFERENCES

1. Anon: United States Navy K-Type Airships. Pilots' Manual. Goodyear Aircraft Corp., Akron, Ohio, 1943.

2. Anon: United States Navy K-Type Airships Maintenance Manual. Goodyear Aircraft Corp., Akron, Ohio.

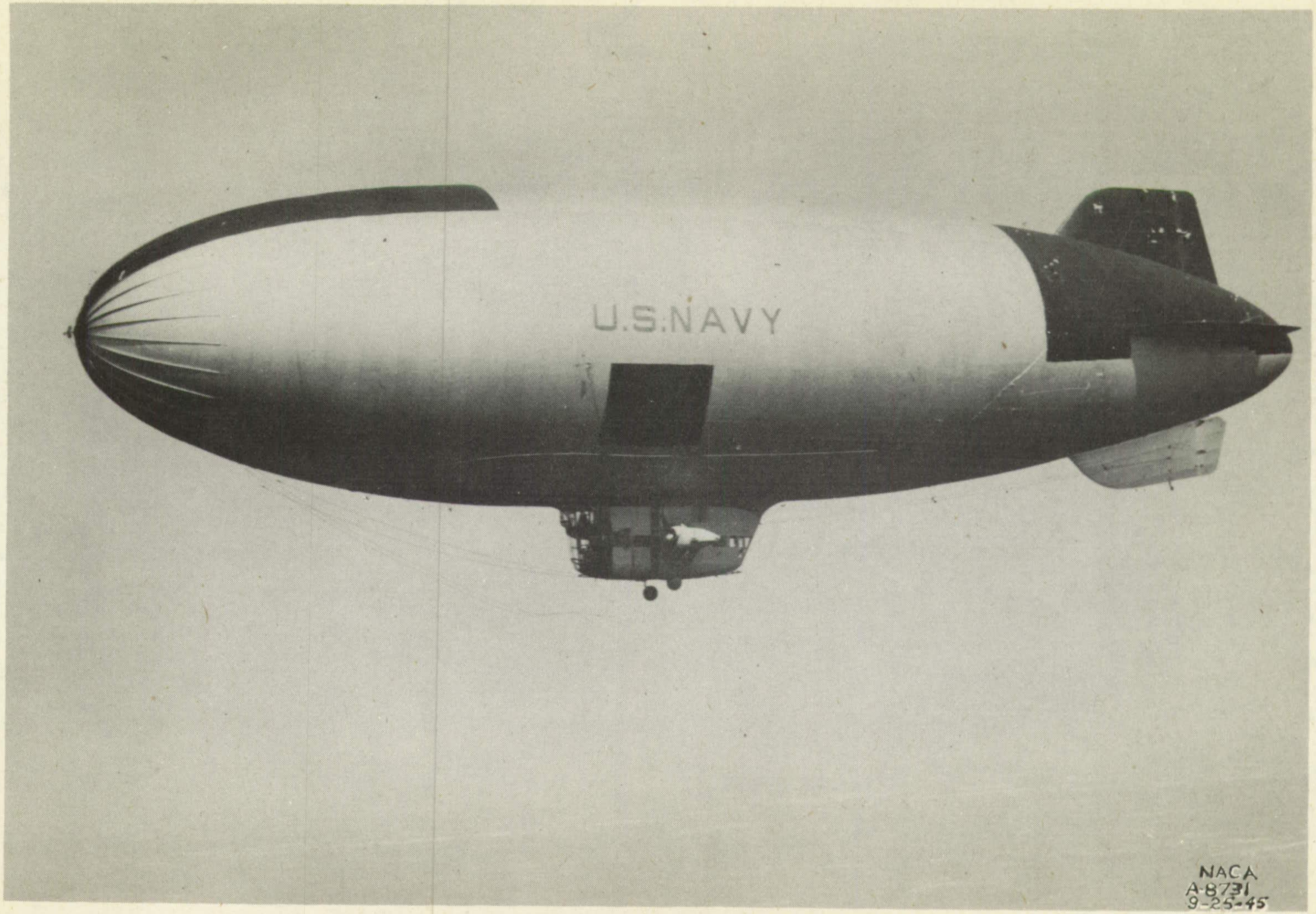


Figure 1.- The K-24 airship equipped for the ice research program.

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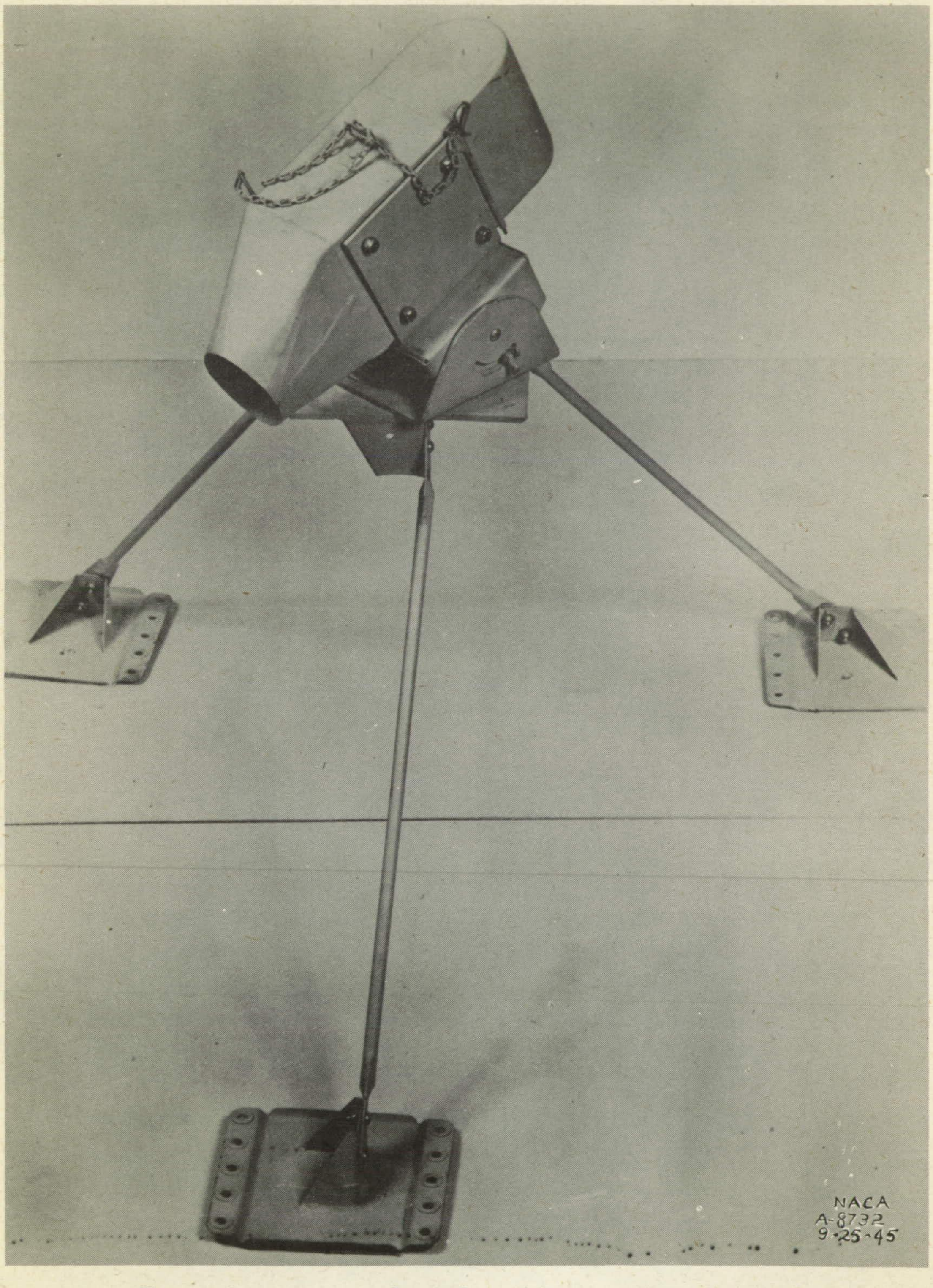


Figure 2.- Typical camera pedestal used in photographing ice on the K-24 envelope, fins, and car.

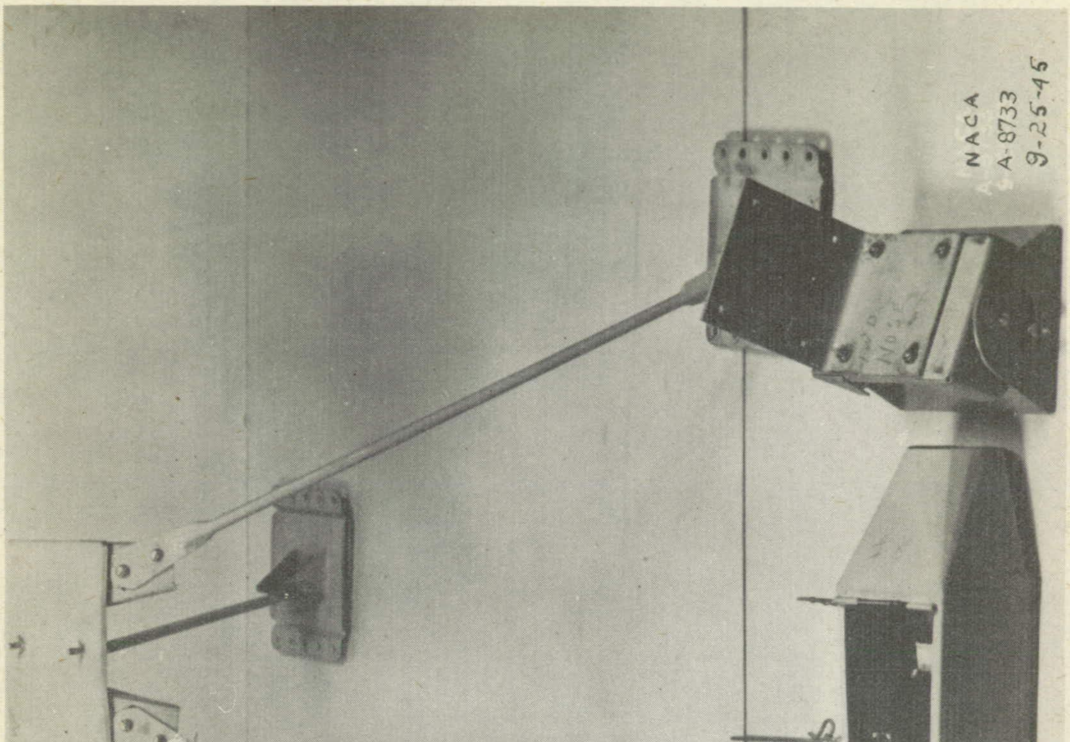


Figure 3.- Camera pedestal disassembled.

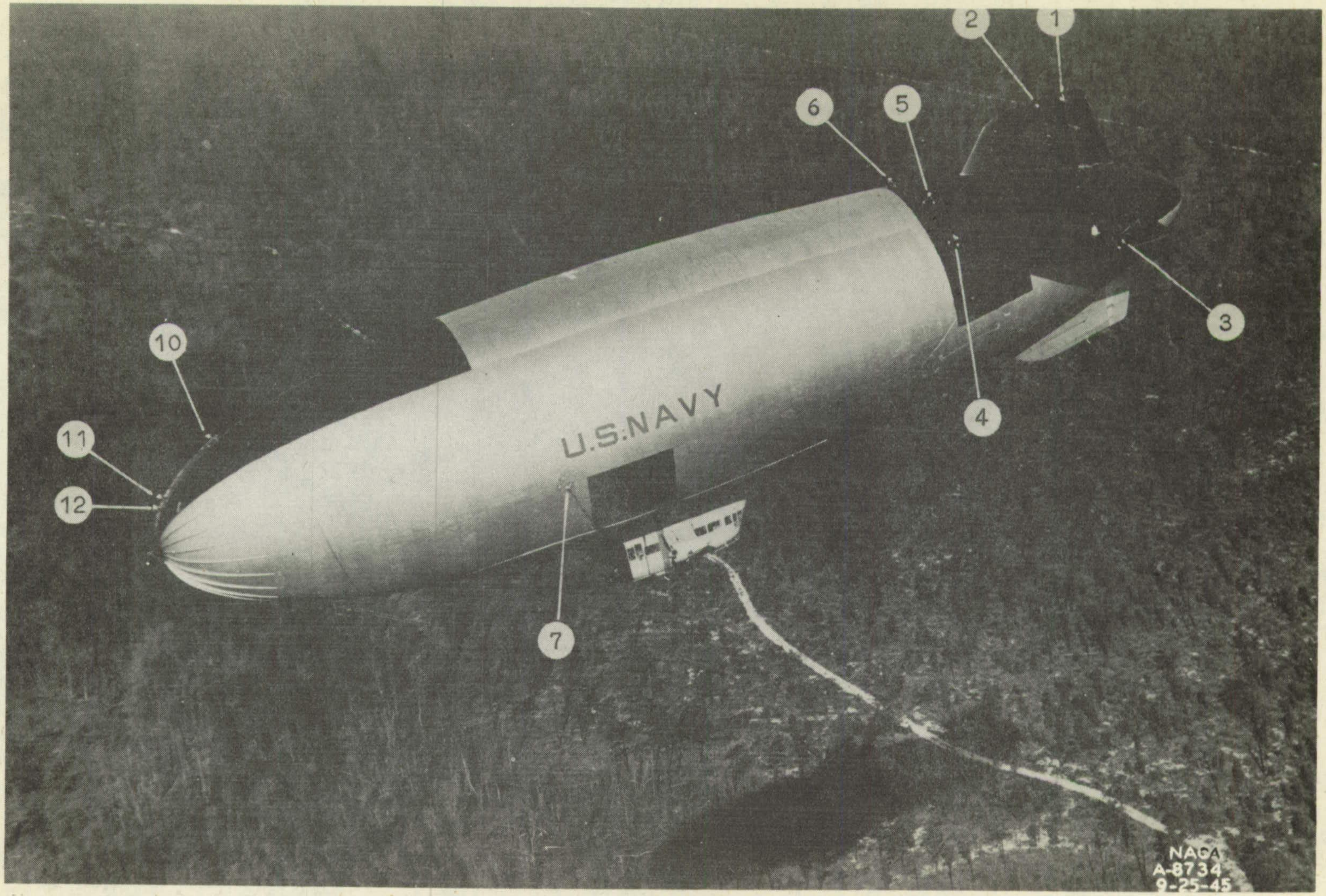


Figure 4.- View of the K-24 airship showing camera positions and areas painted black on top of the envelope and fins.

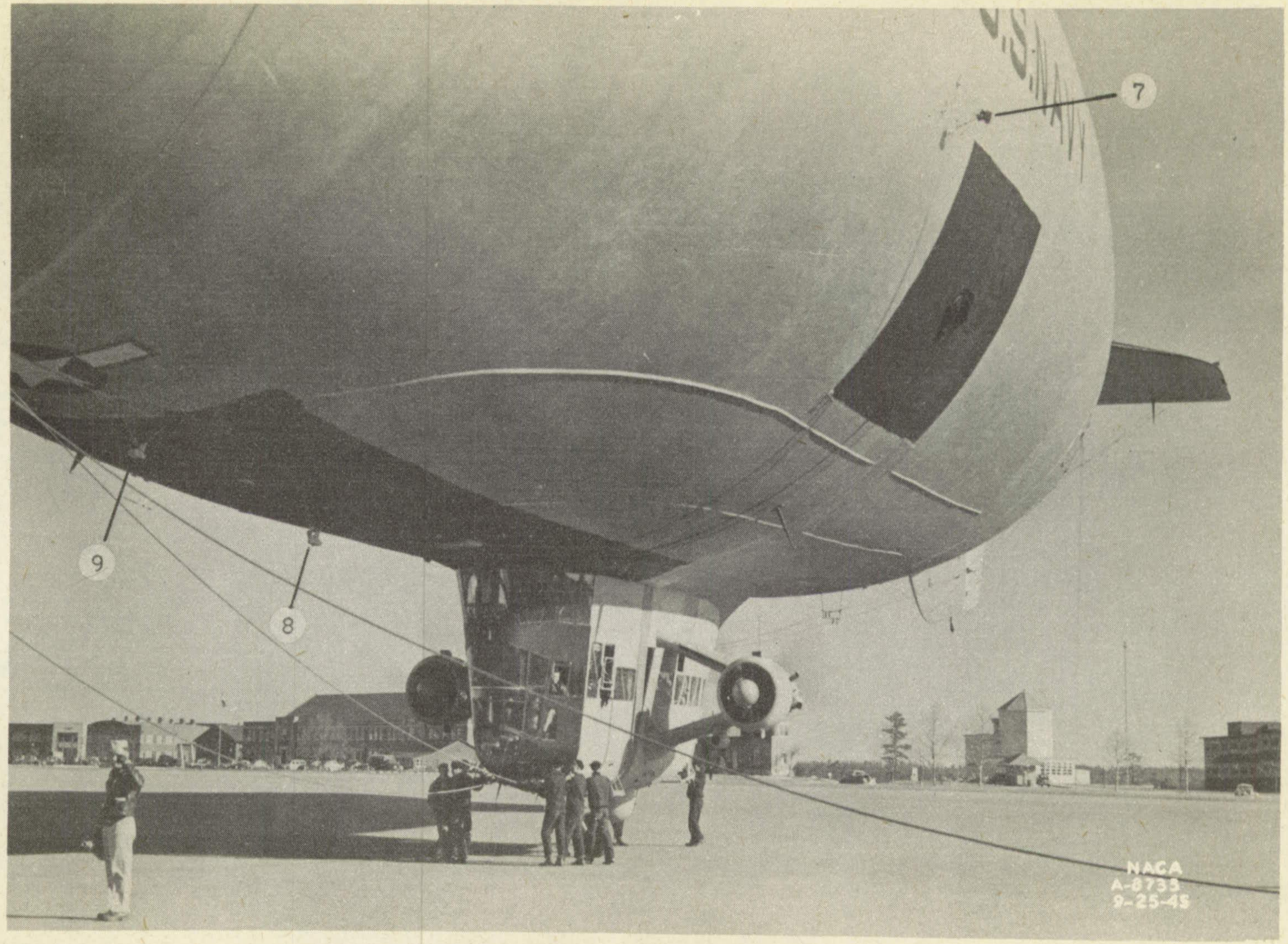


Figure 5.- View of the K-24 airship showing camera positions and areas painted black around the car.

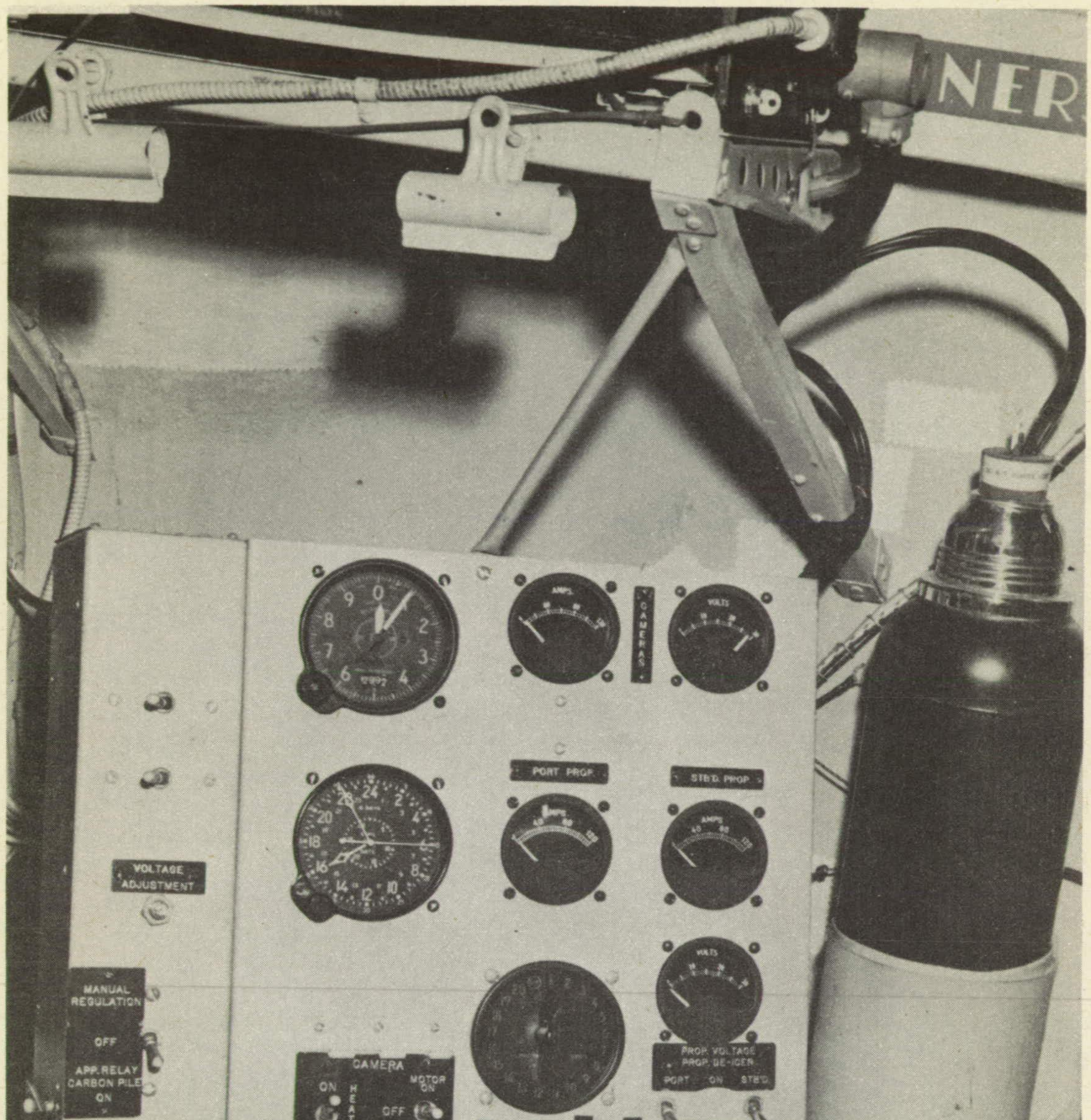


Figure 6.- Ice research instrument panel on the K-24 airship navigator's table.

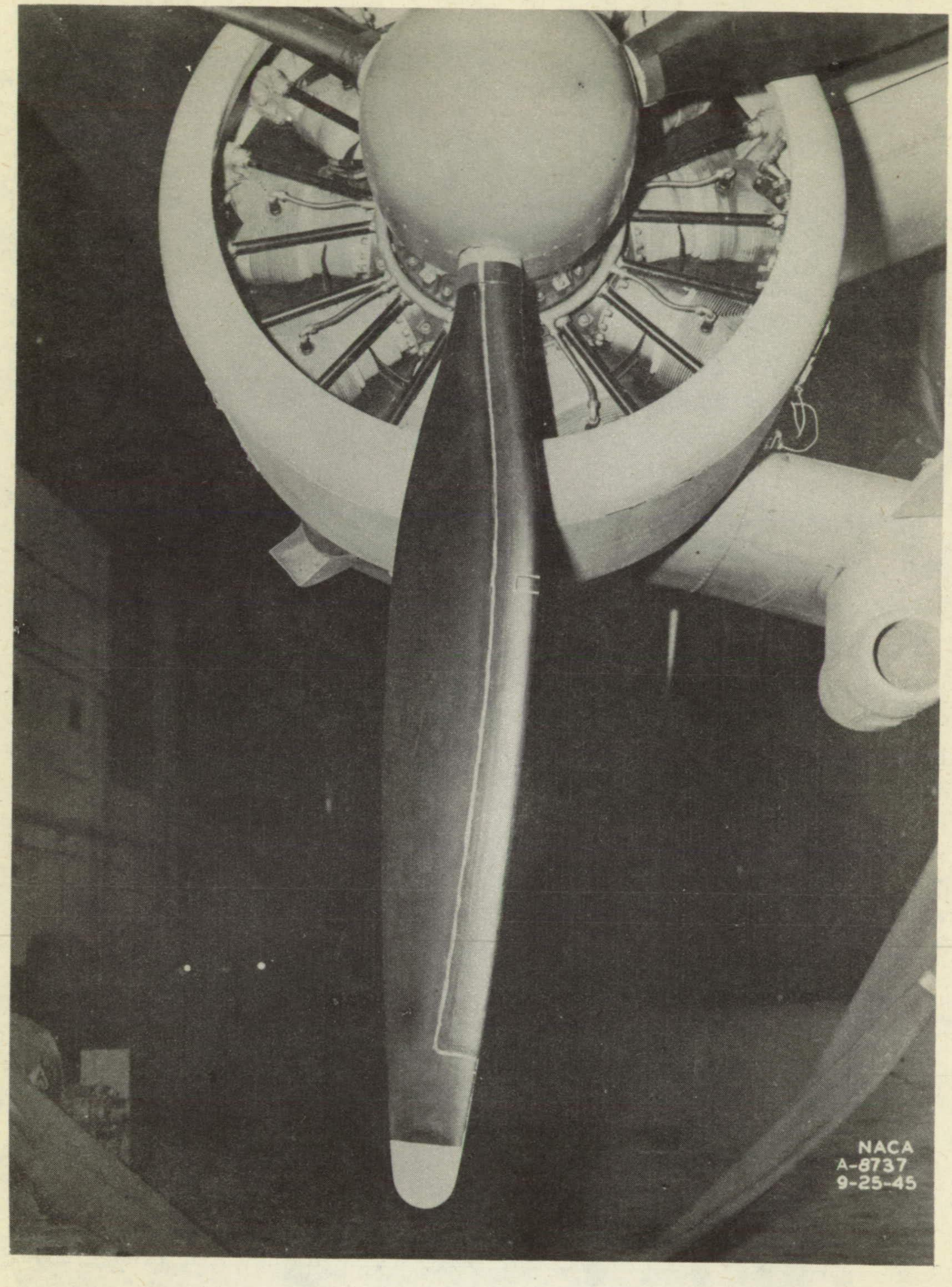


Figure 7.- Camber face of blade of 12 foot-6 inch diameter fixed-pitch propeller on the K-24 airship equipped with thermal-electric blade shoe.

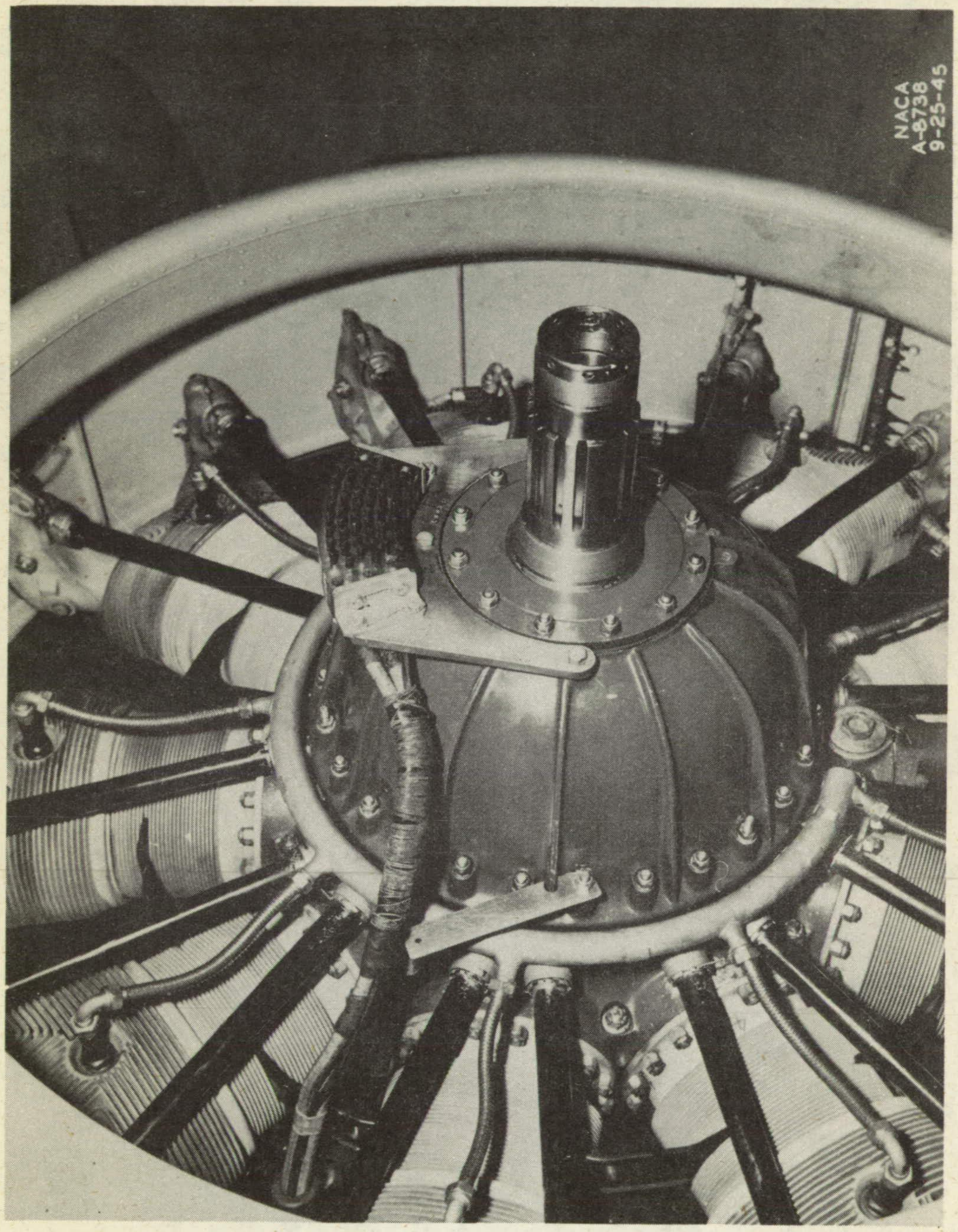


Figure 8.- Propeller brush block assembly mounted on the starboard engine of the K-24 airship. Port propeller assembly is identical.

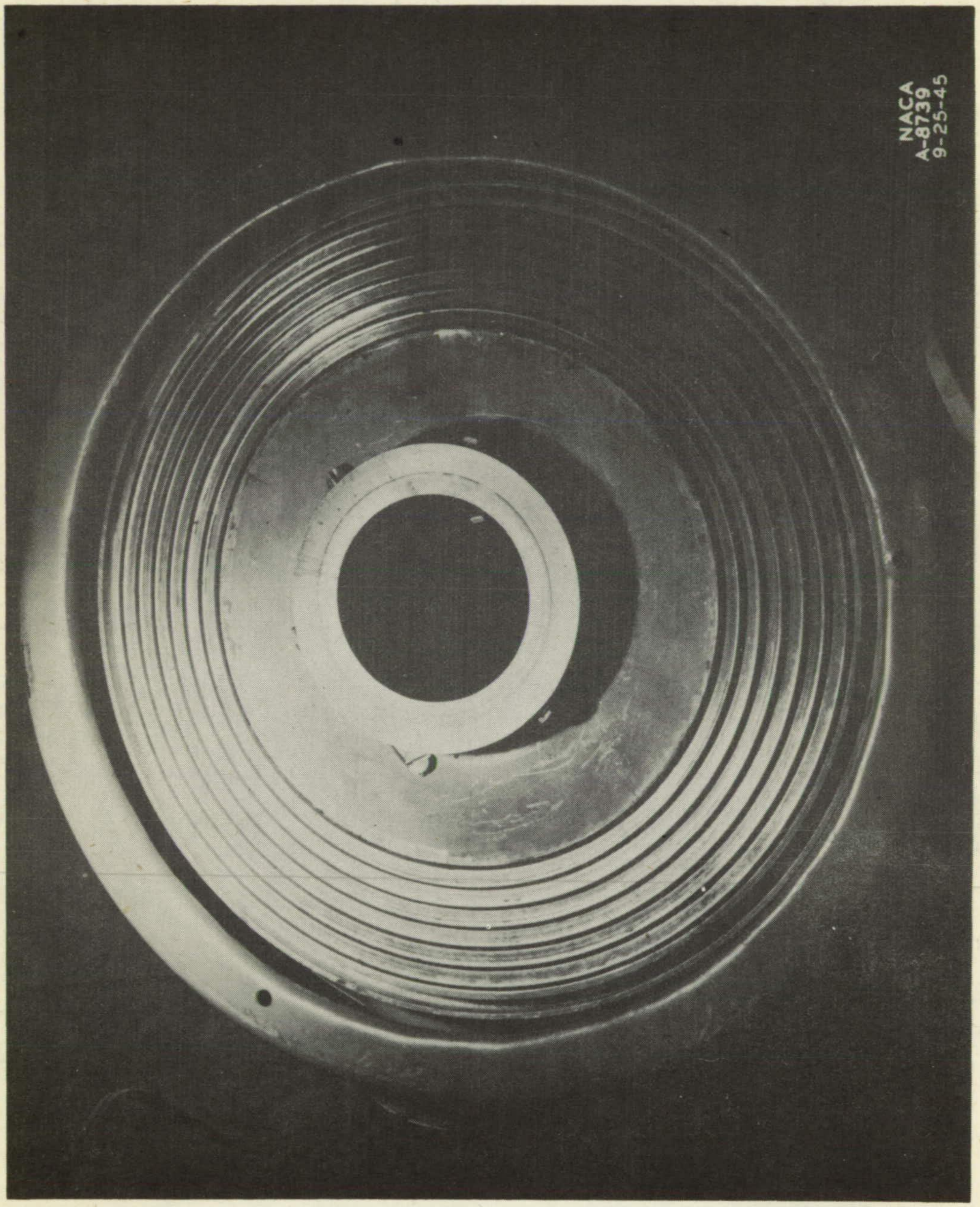


Figure 9.- Bearing face of the slip rings mounted on the K-24 airship propeller hubs.

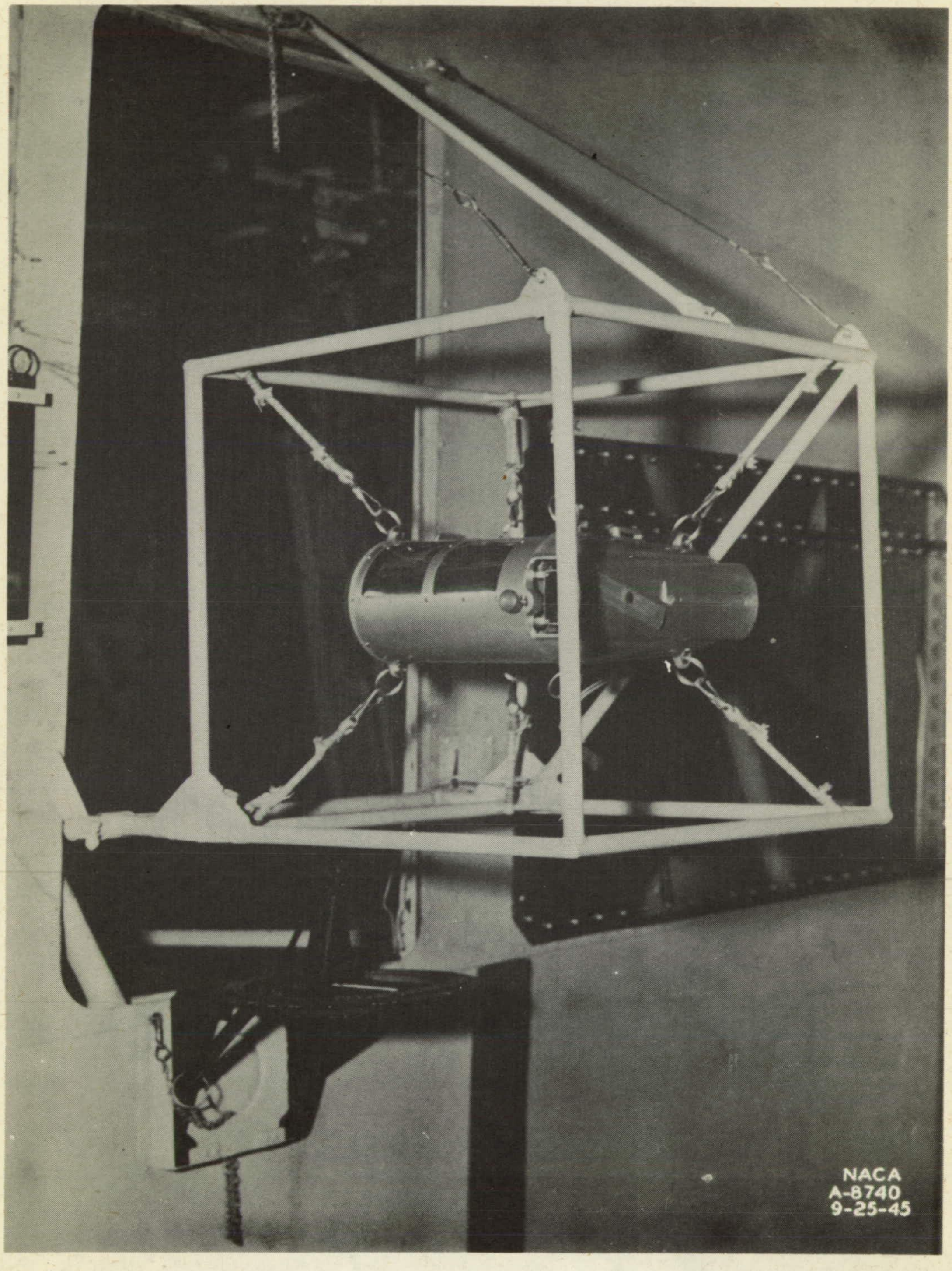


Figure 10.- Aerograph mounted on the port side of the K-24 airship car at the navigator's window.

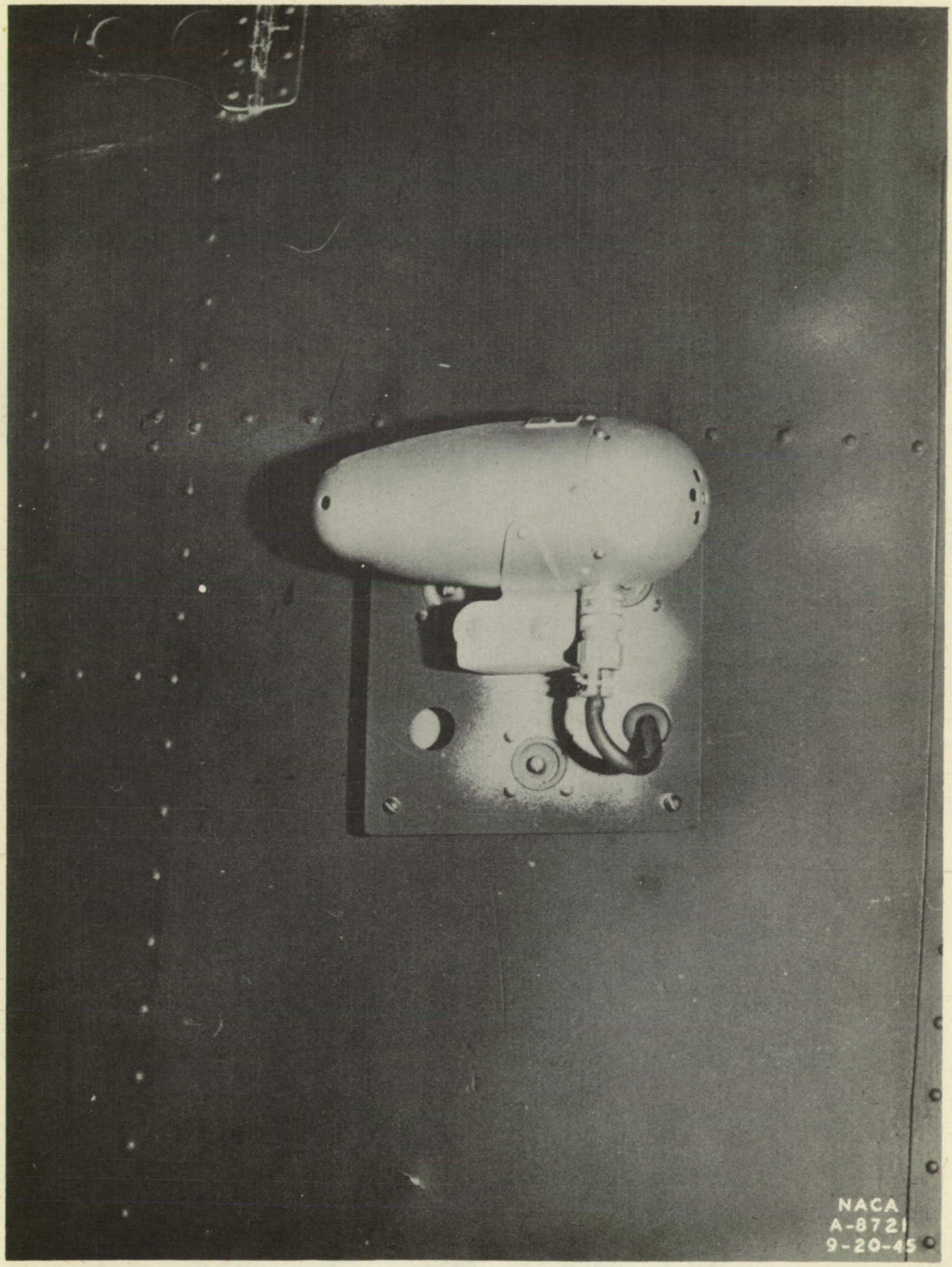


Figure 11.- Electrical humidity transmitter located on the starboard side of the K-24 airship car at the rudderman's window.

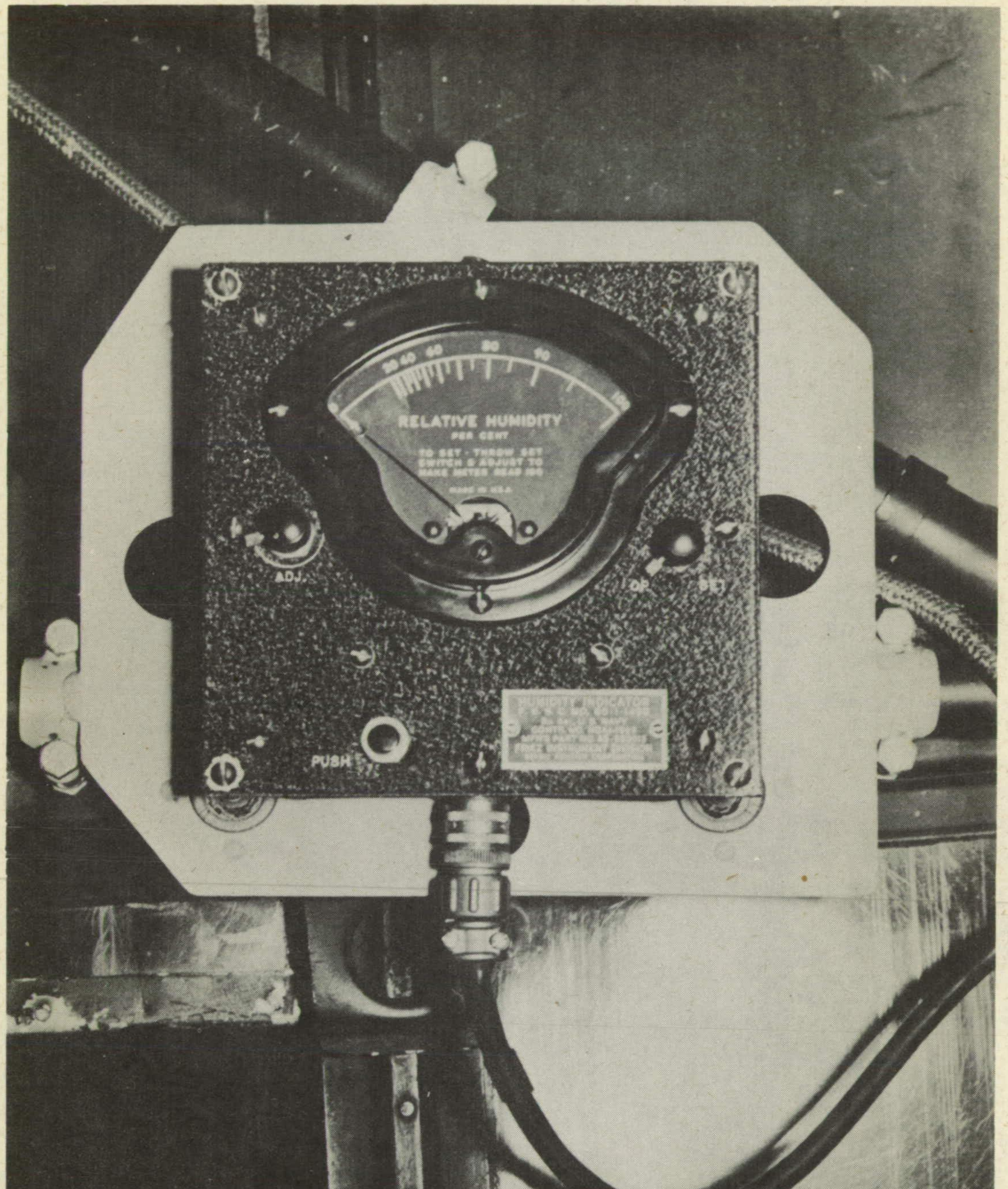


Figure 12.- Electrical humidity indicator located above the rudderman's window in the K-24 airship car.

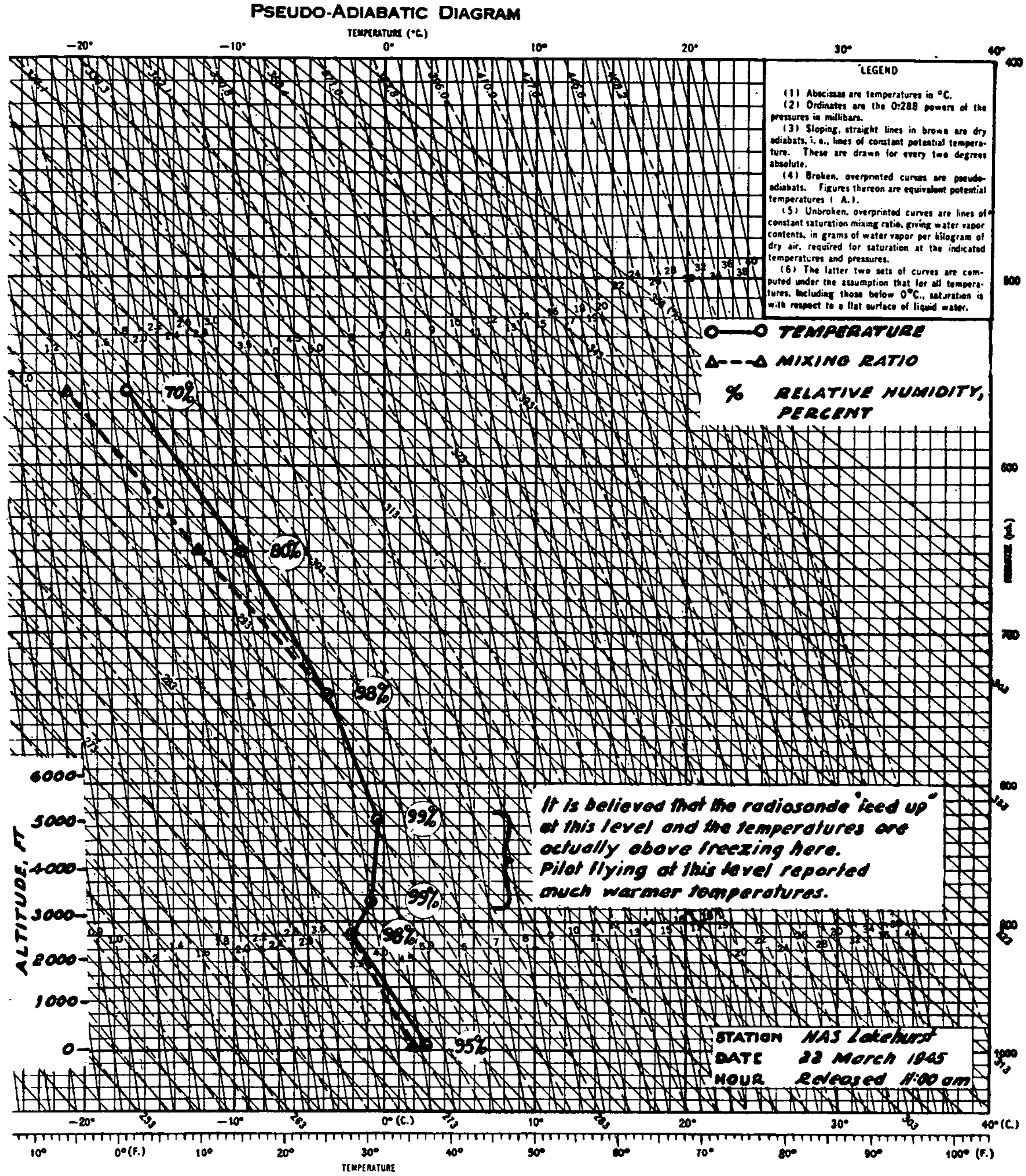


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Figure 13.- Record of radio sonde released at 11:00 a. m. on Mar. 22, 1945.

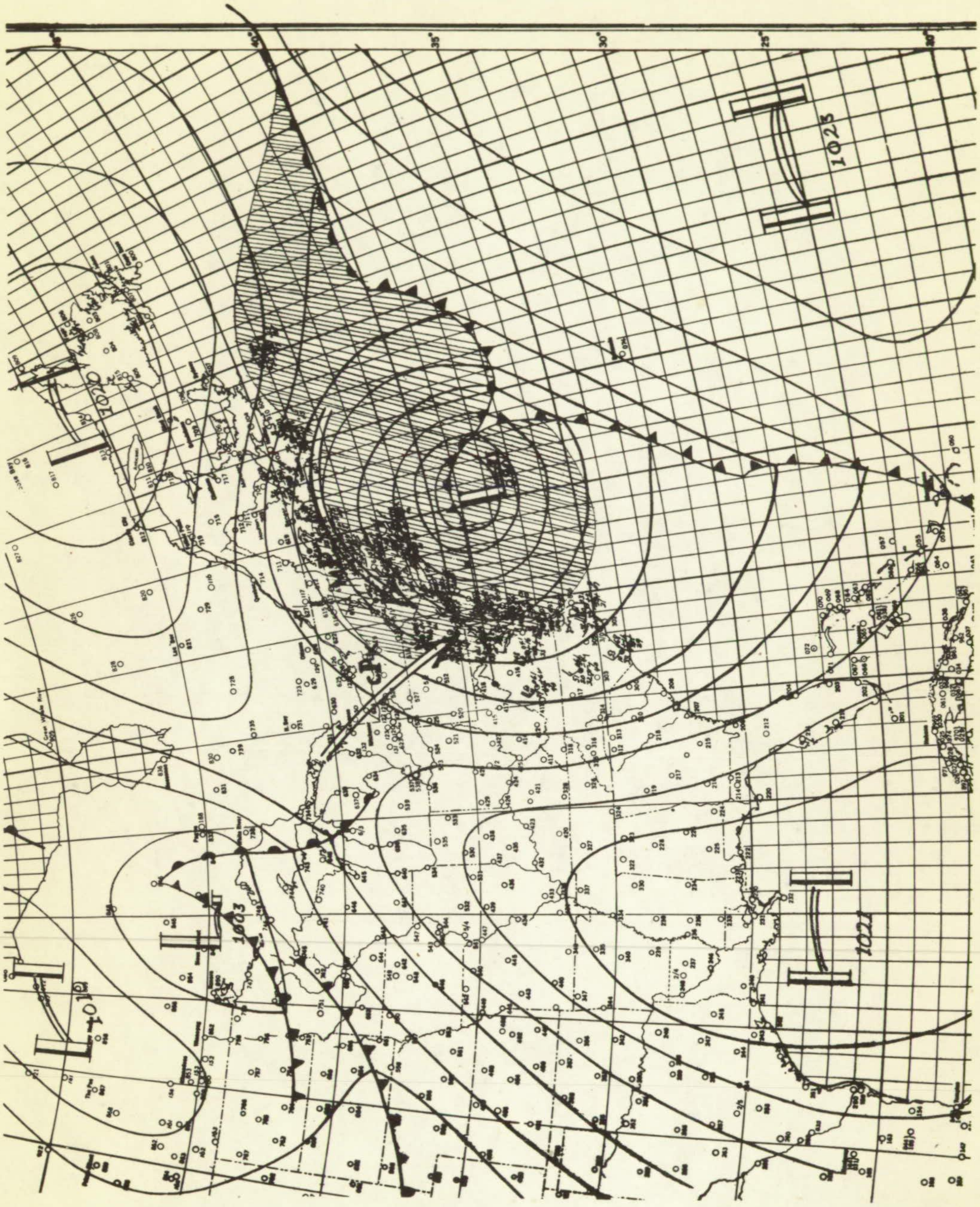


Figure 14.- Weather map for Mar. 22, 1945 at 2:30 p. m.

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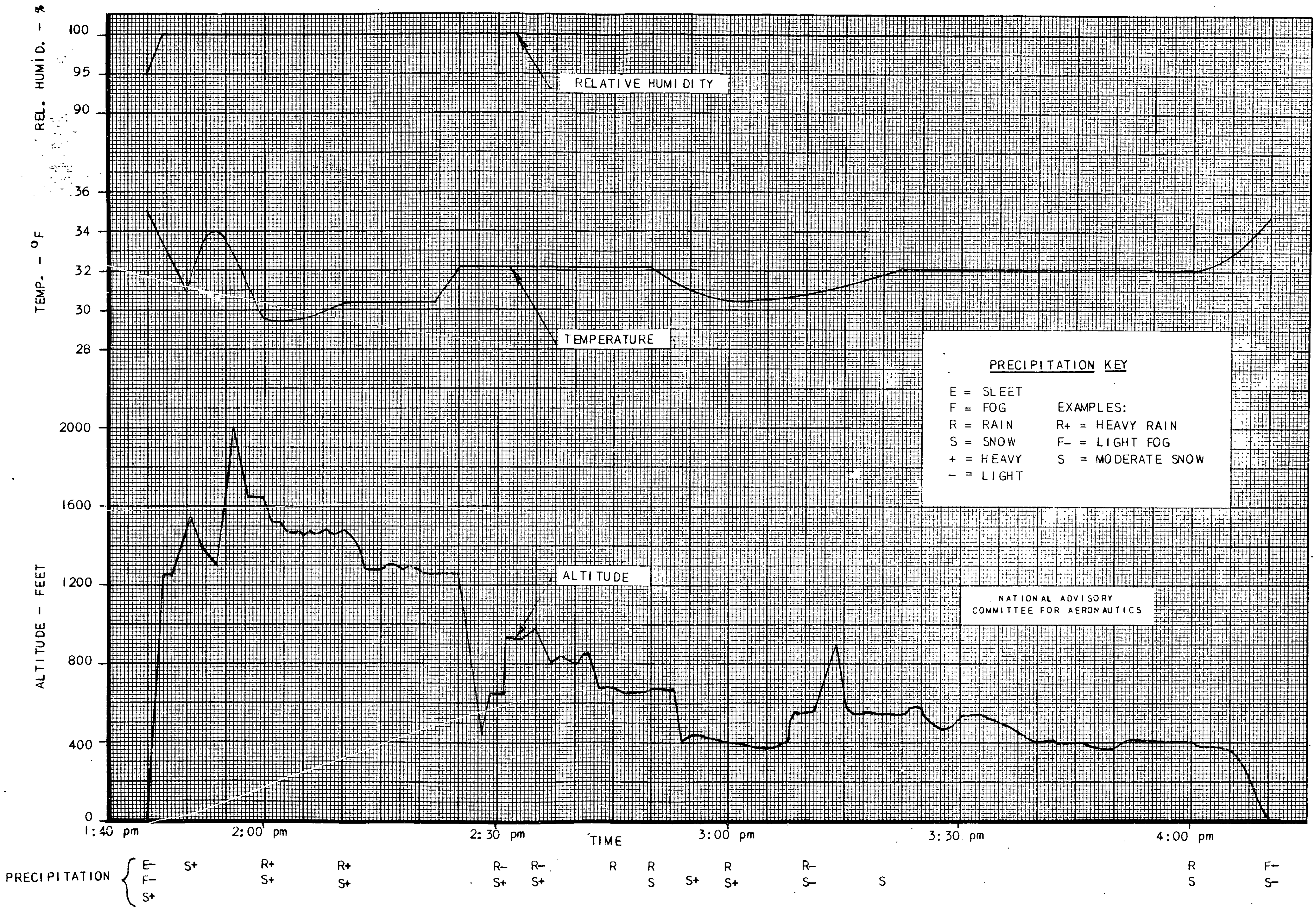



FIGURE 15. - AEROGRAPH RECORDS OF RELATIVE HUMIDITY, TEMPERATURE AND ALTITUDE FOR THE K-24 AIRSHIP FLIGHT ON MARCH 22, 1945.

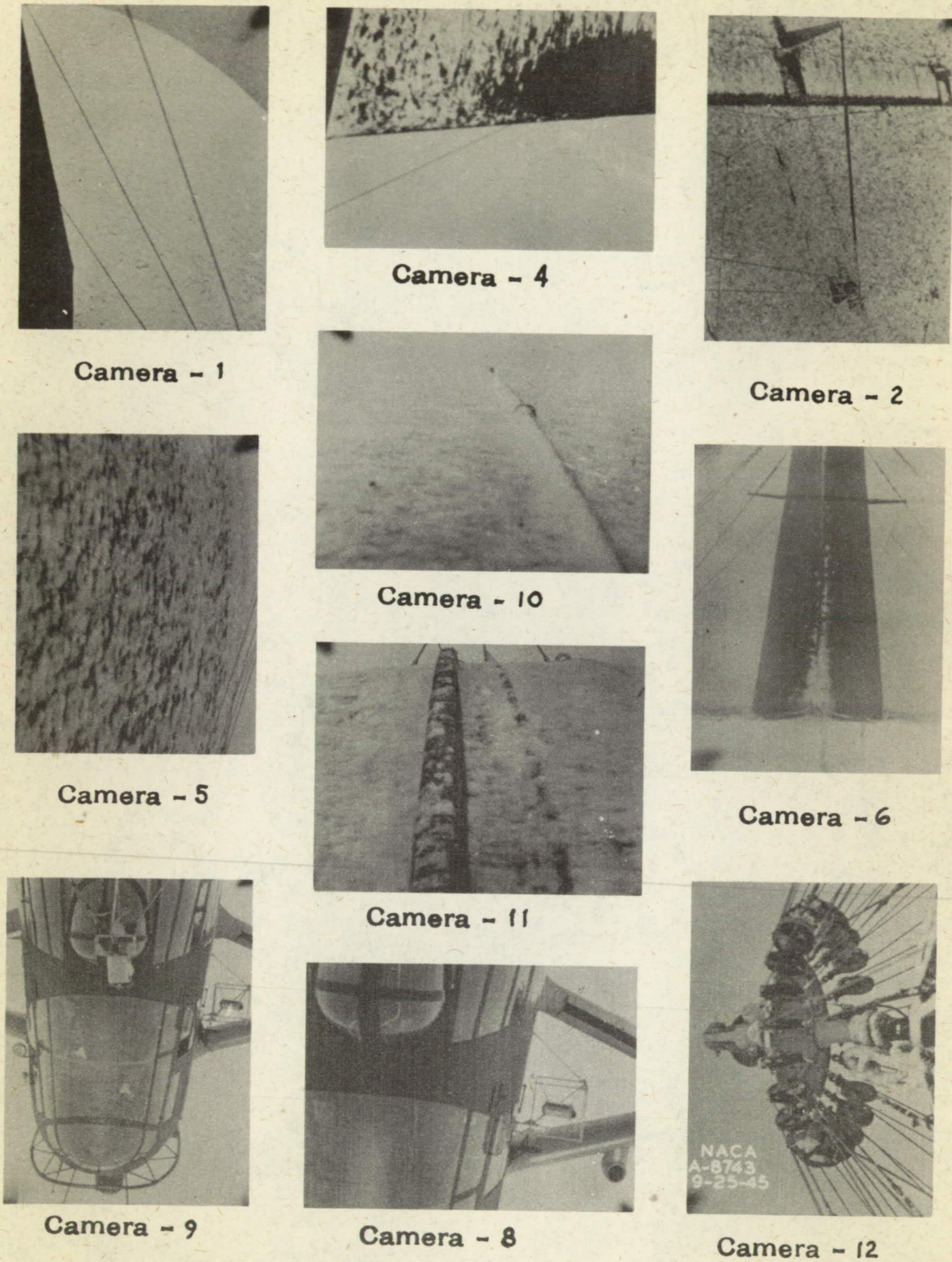



Figure 16.- Condition of the K-24 airship envelope, fins, and car at 1:50 p. m., Mar. 22, 1945; 5 minutes after take-off.

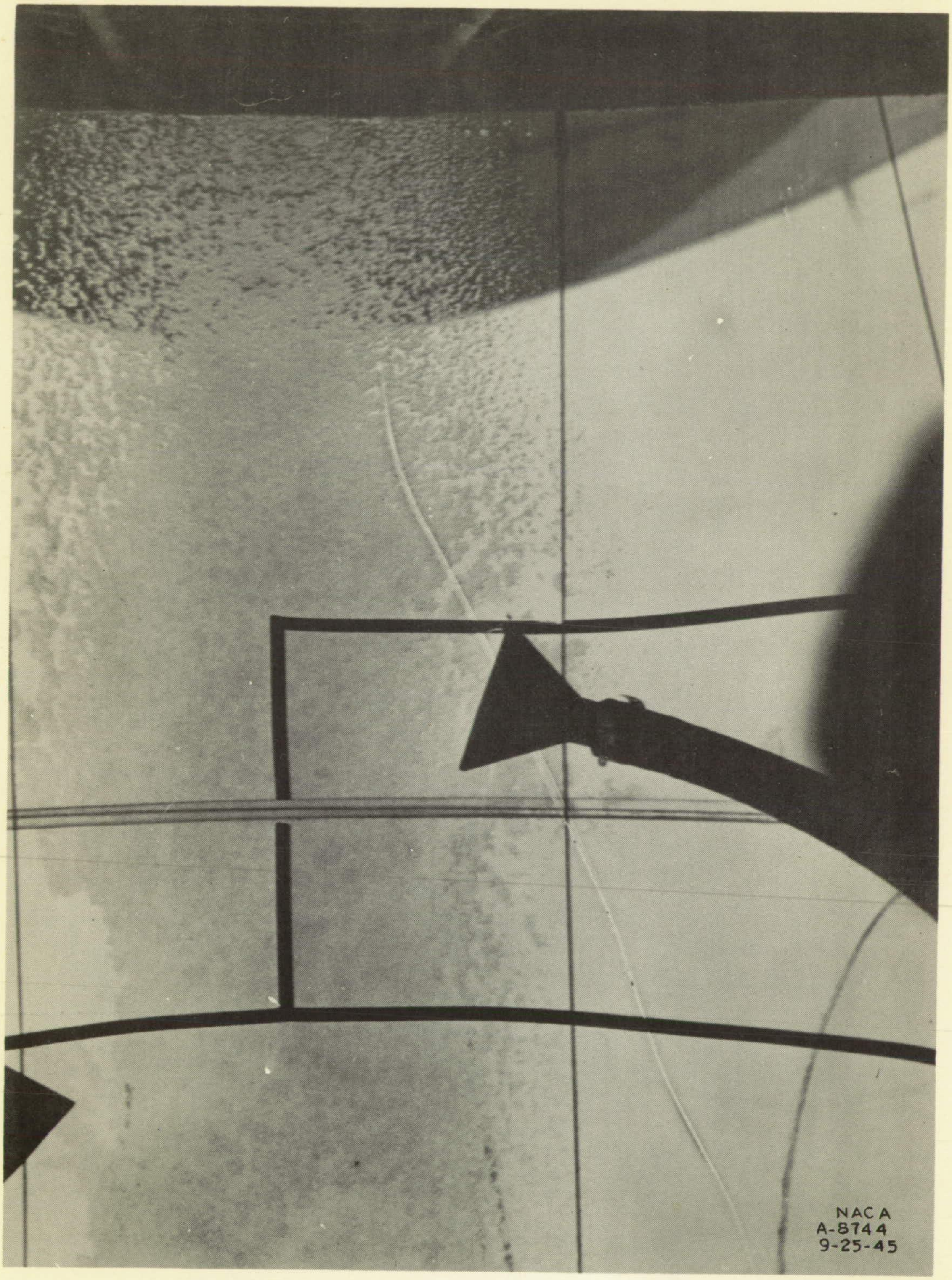



Figure 17.- Ice on the forward window of the K-24 airship car at 2:05 p. m., Mar. 22, 1945.

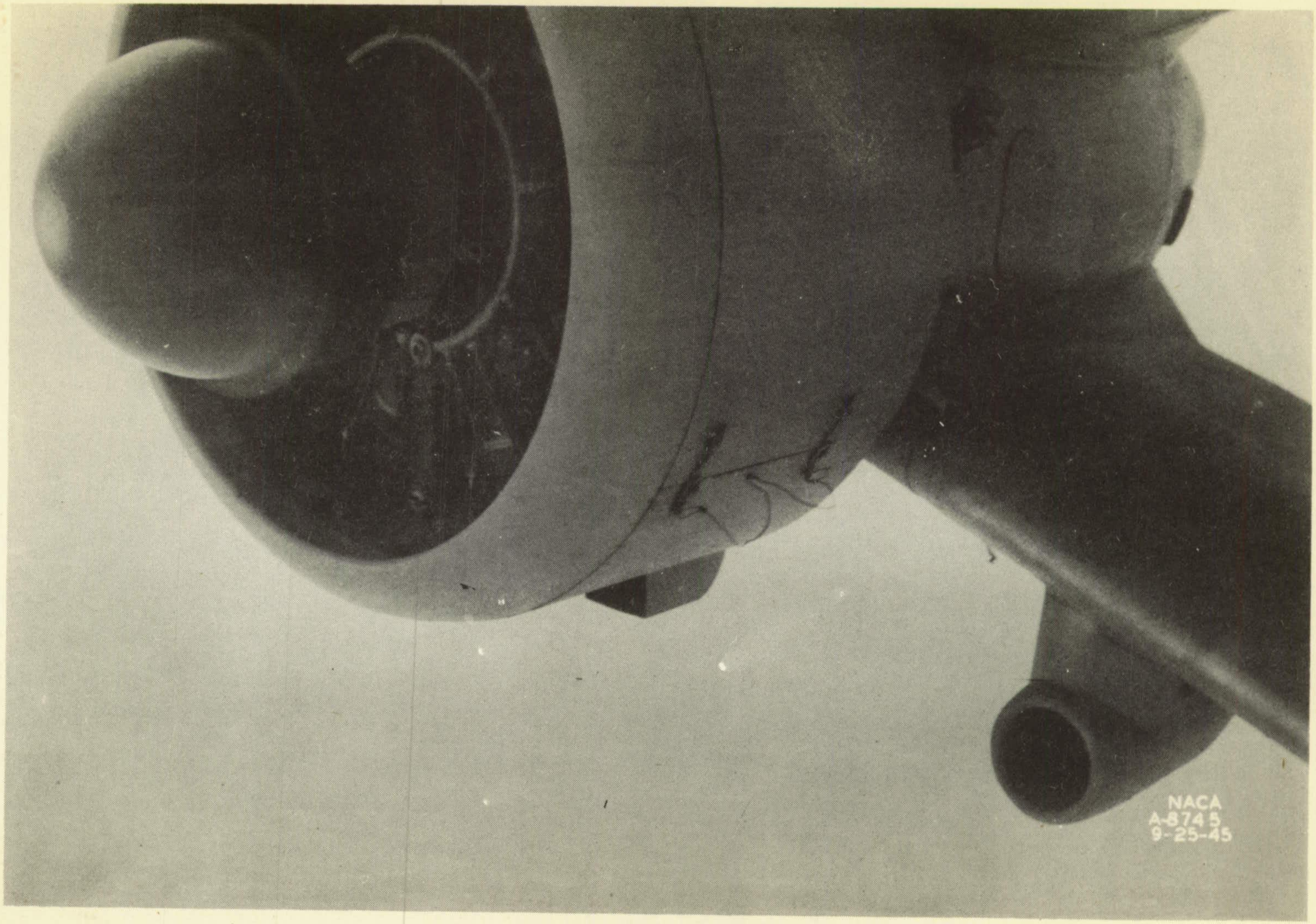



Figure 18.- Ice on the starboard engine outrigger of the K-24 airship at 2:06 p. m., Mar. 22, 1945.

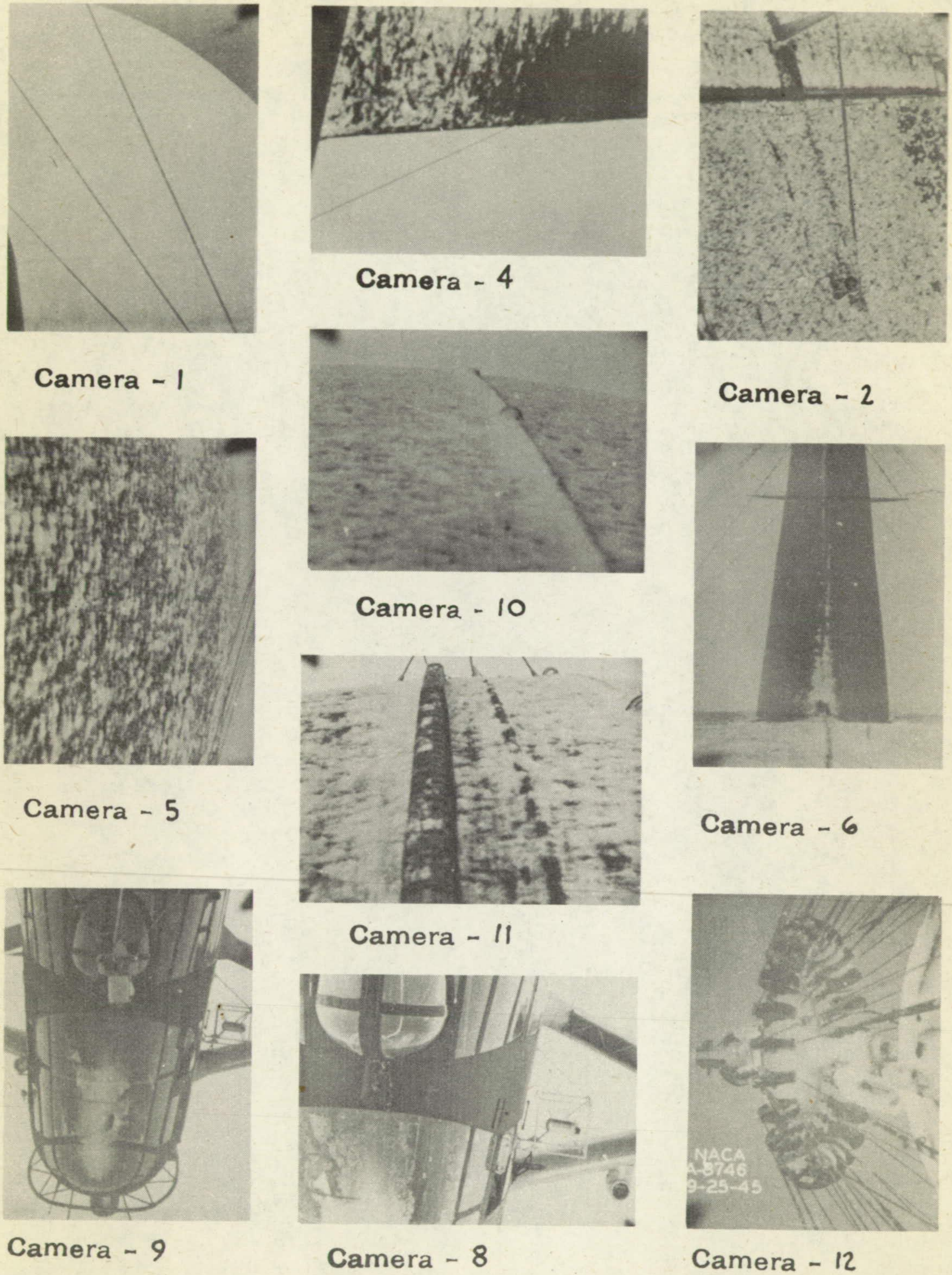



Figure 19.- Condition of the K-24 airship envelope, fins, and car at 2:32 p. m., Mar. 22, 1945.

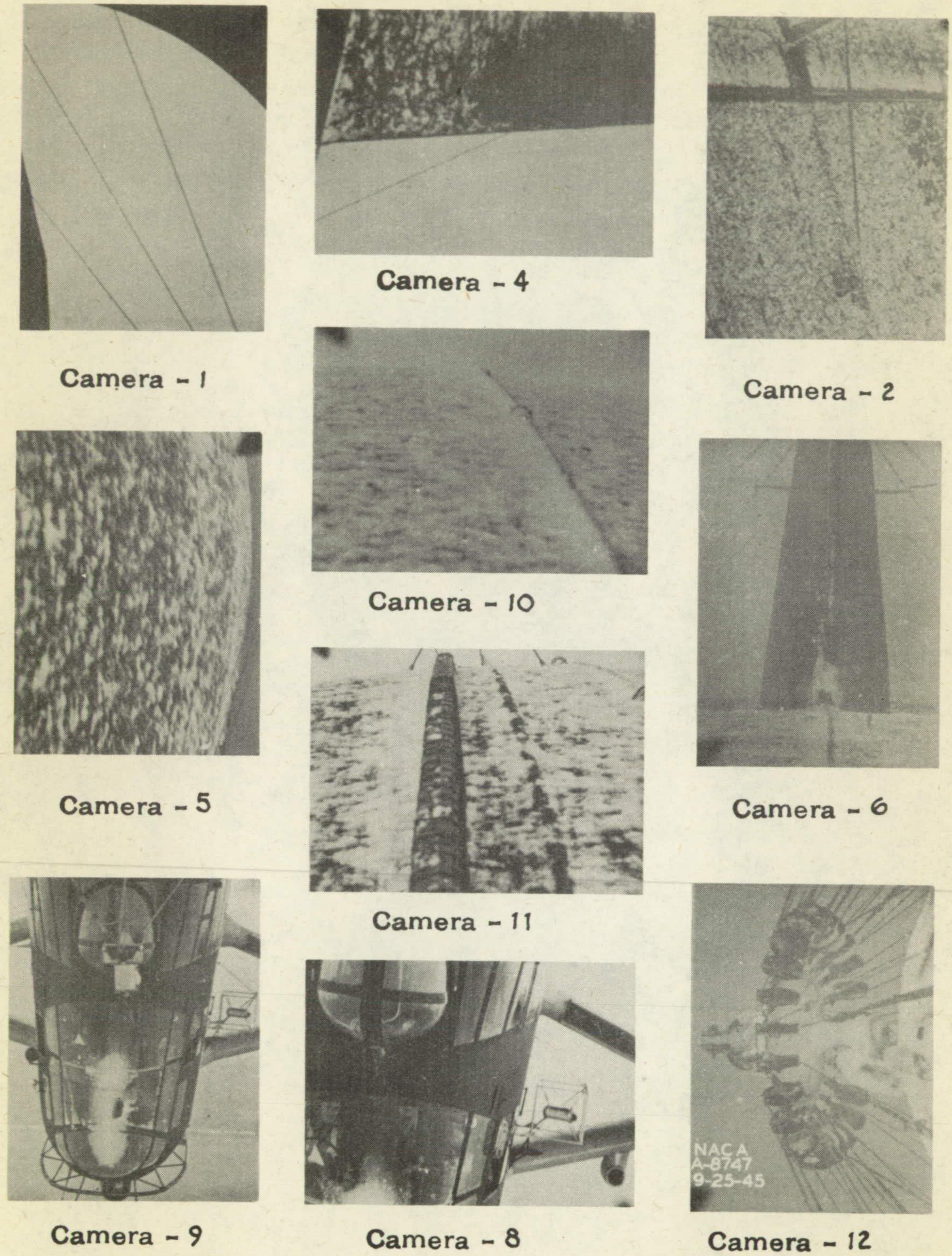



Figure 20.- Condition of the K-24 airship envelope, fins, and car at 2:45 p. m., Mar. 22, 1945.

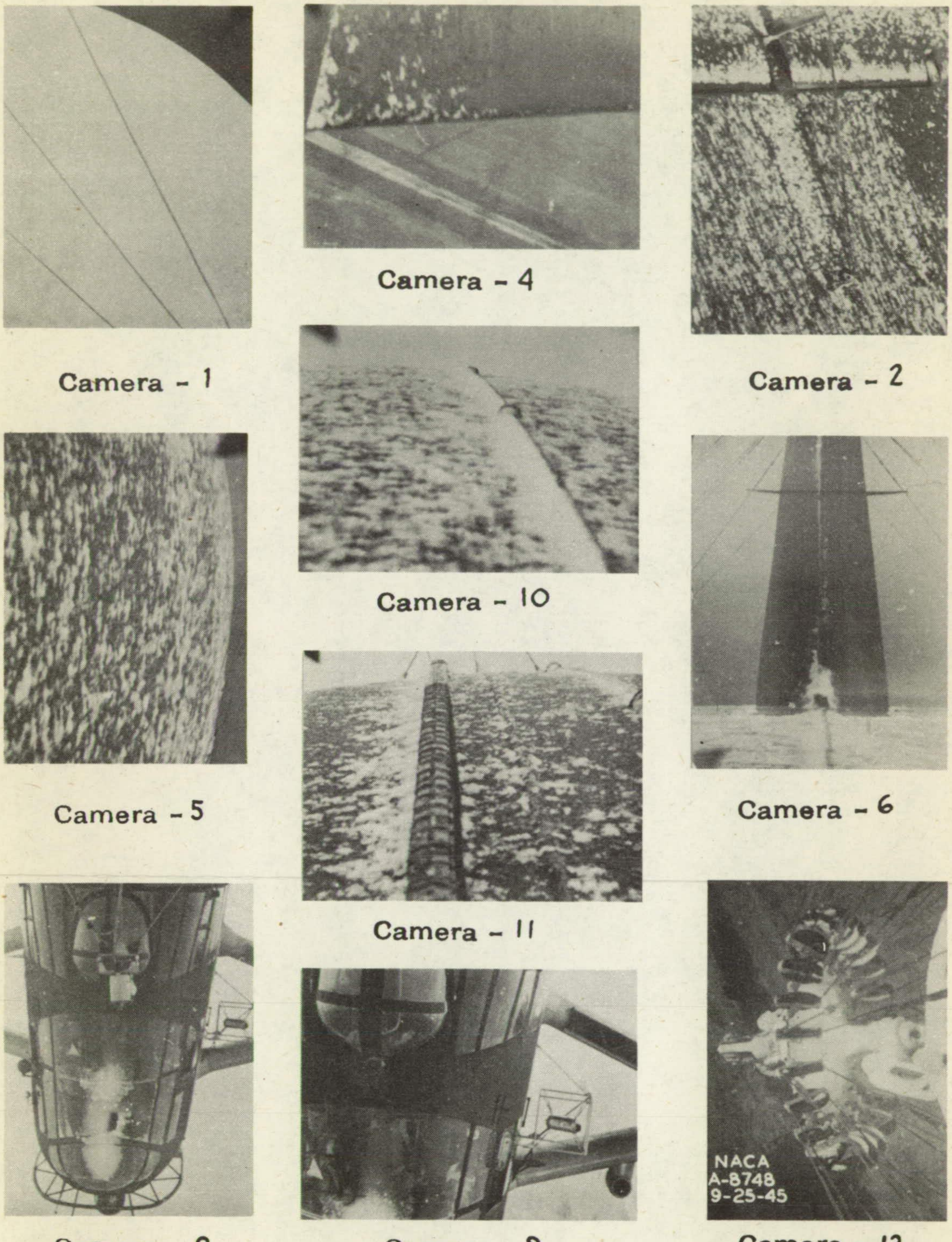



Figure 21.- Condition of the K-24 airship envelope, fins, and car at 2:46 p.m., Mar. 22, 1945.

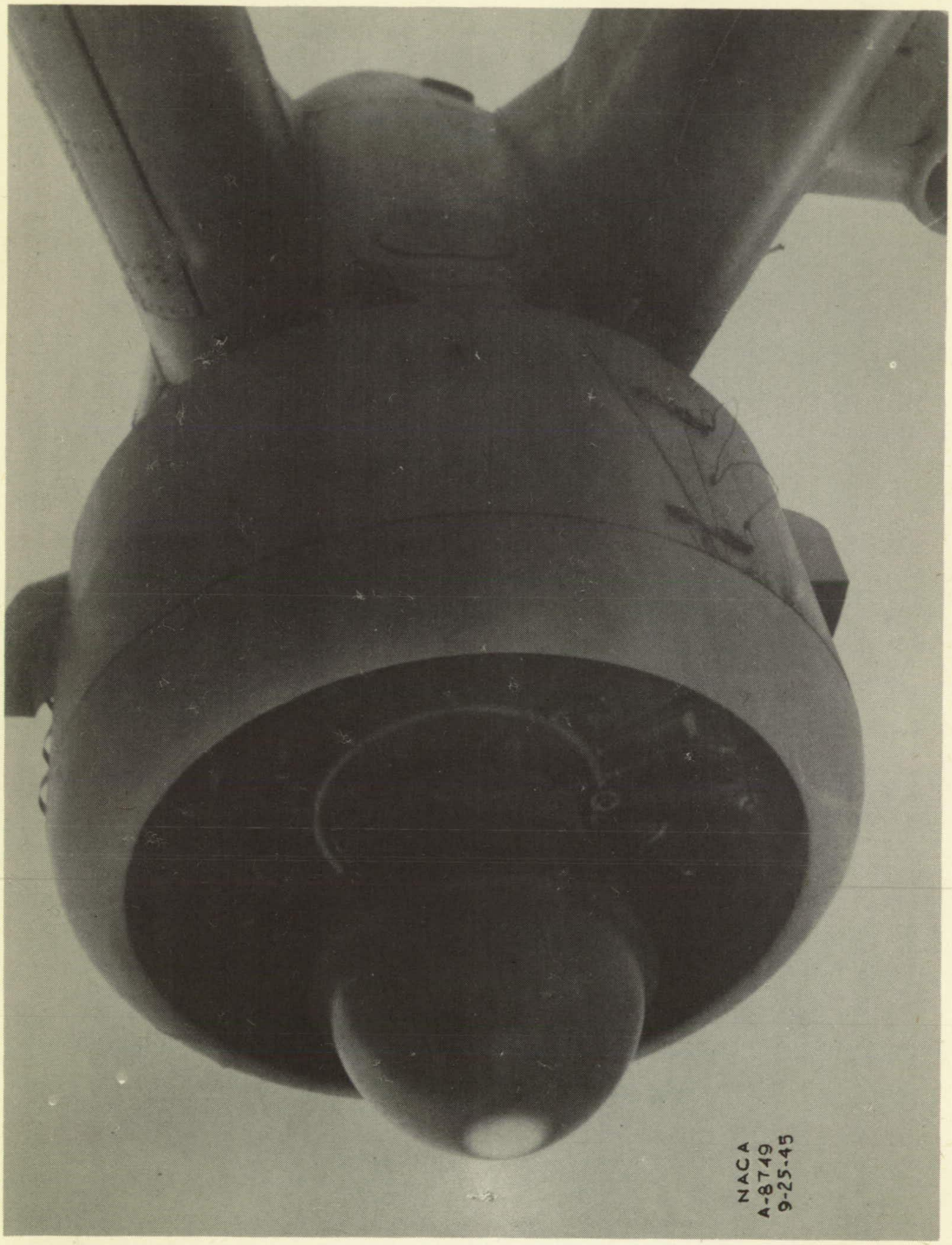



Figure 22.- Ice on the K-24 airship outrigger at 3:01 p. m., Mar. 22, 1945.

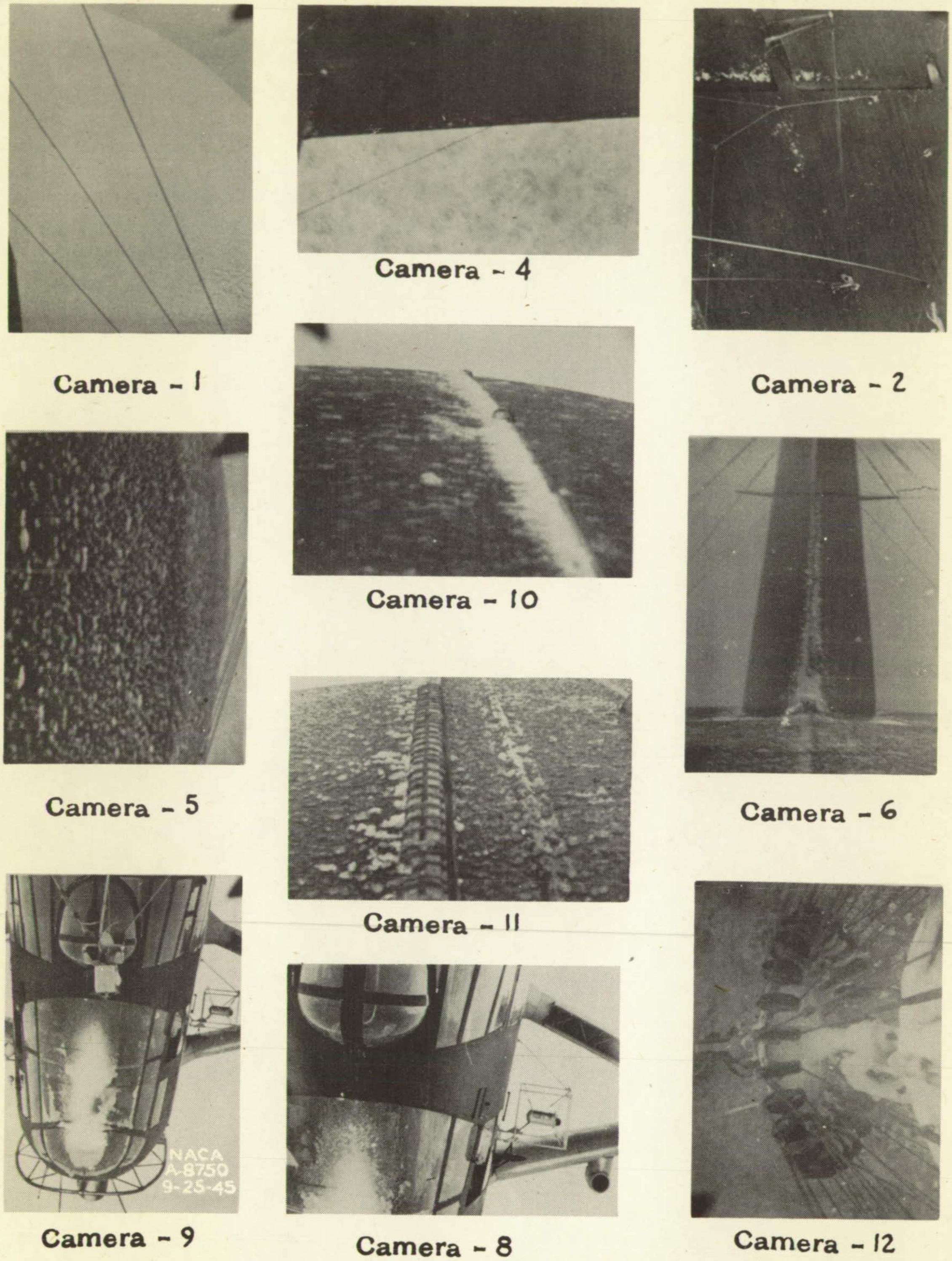



Figure 23.- Condition of the K-24 airship envelope, fins, and car at 3:10 p. m., Mar. 22, 1945.

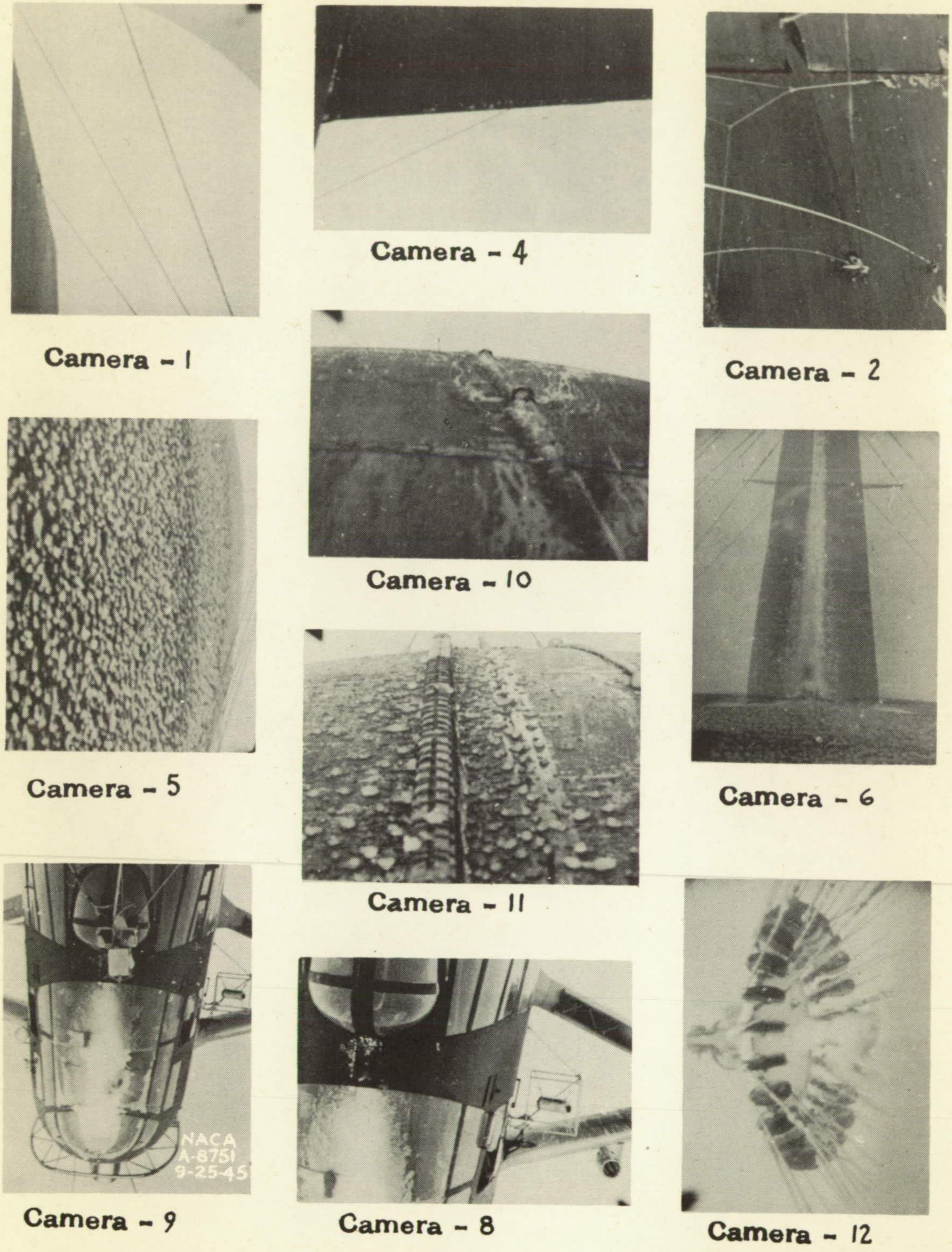



Figure 24.- Condition of the K-24 airship envelope, fins, and car at 3:40 p. m., Mar. 22, 1945.


Figure 25.- Ice on the K-24 airship port outrigger at 3:45 p. m., Mar. 22, 1945.

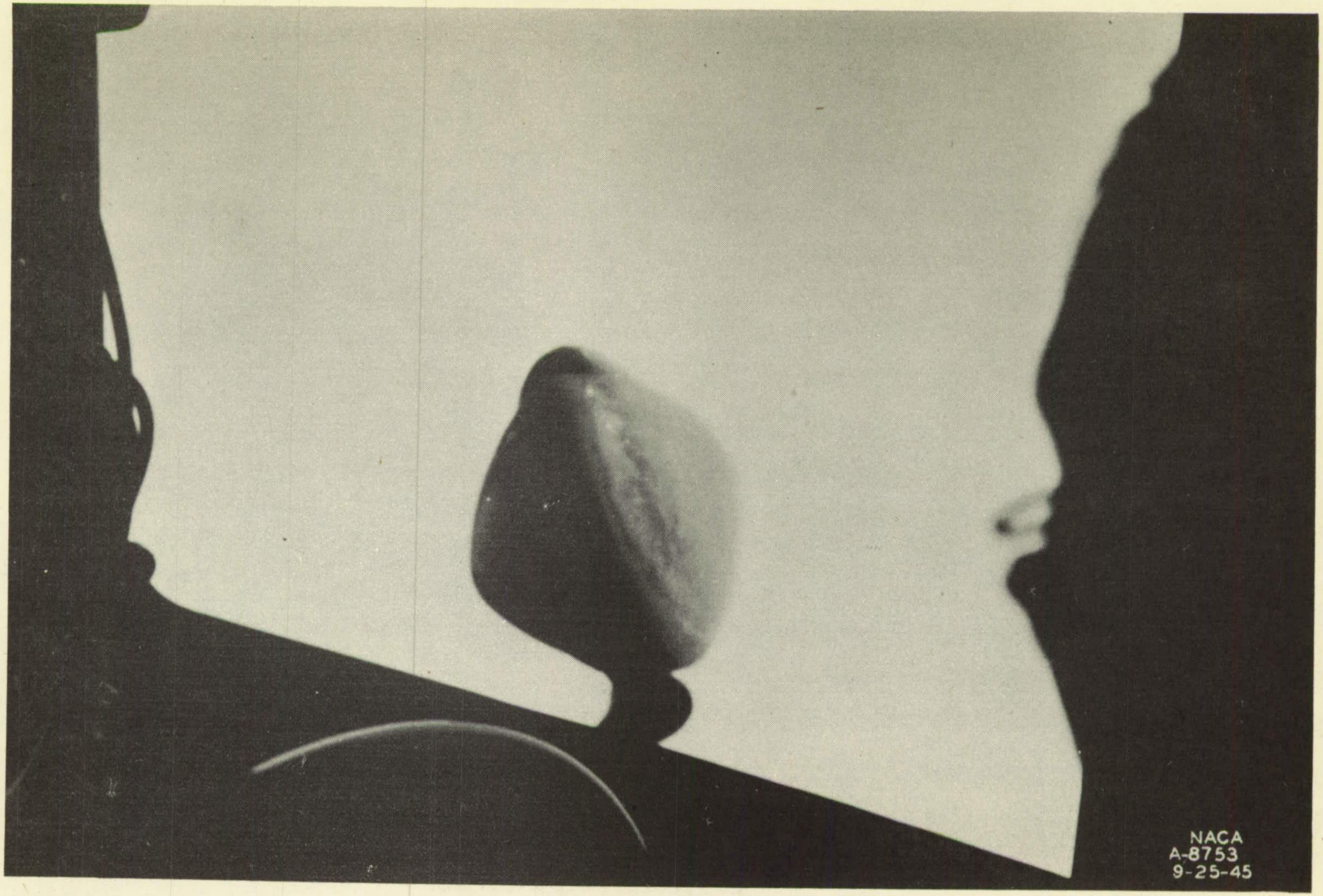



Figure 26.- Ice on the K-24 airship spotlight at the rudderman's window at 3:45 p. m., Mar. 22, 1945.

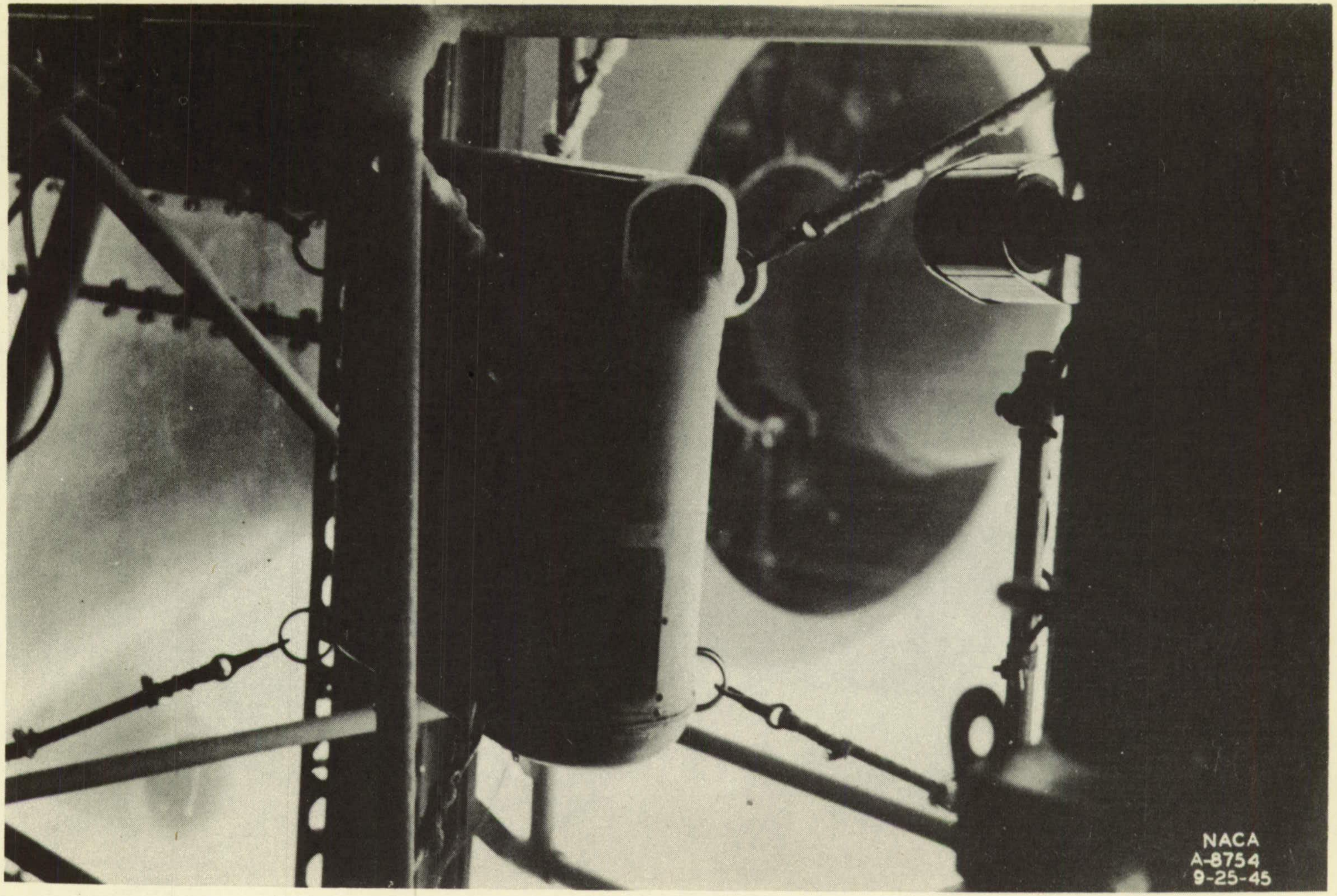



Figure 27.- Ice on the aerograph at 3:50 p. m., Mar. 22, 1945. (Frame swung inside car.)

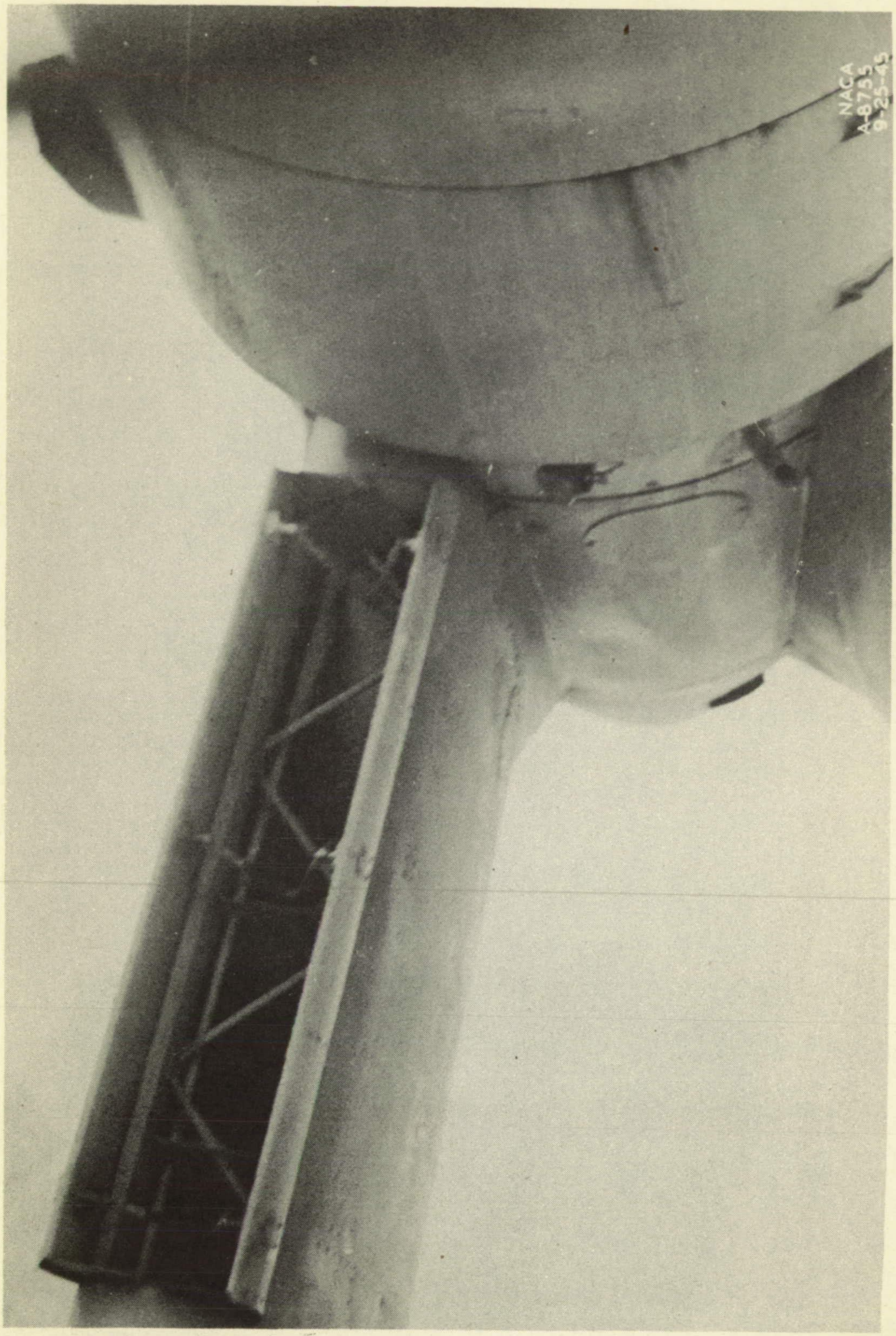
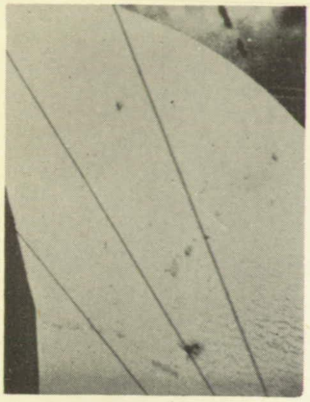
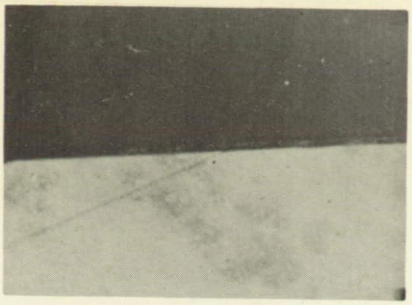


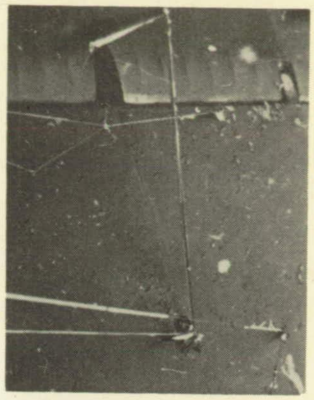

Figure 28.- Ice on the K-24 airship port air scoop at 3:55 p. m., Mar. 22, 1945.



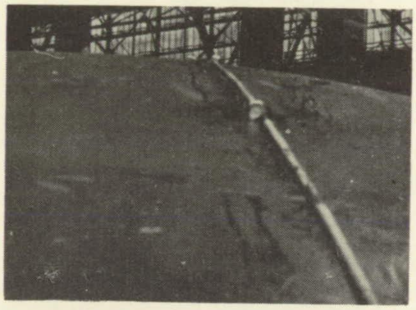
Camera - 1



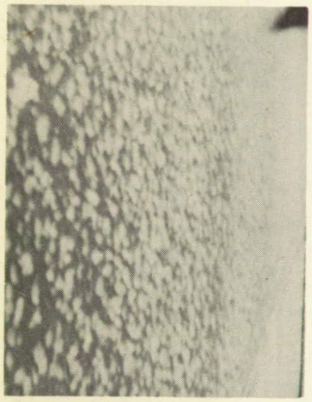
Camera - 4



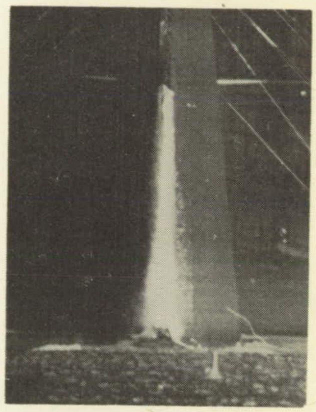
Camera - 2



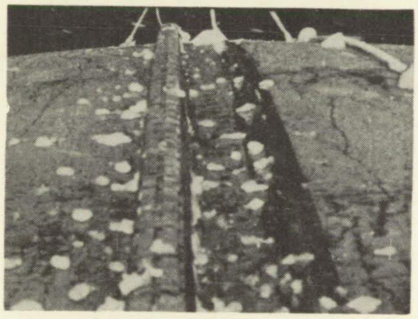
Camera - 10



Camera - 5

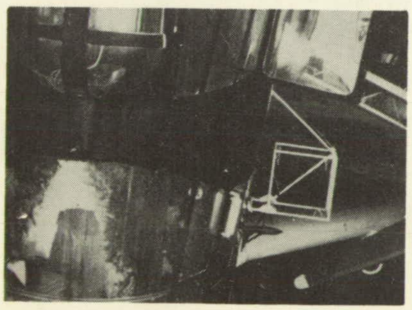


Camera - 6

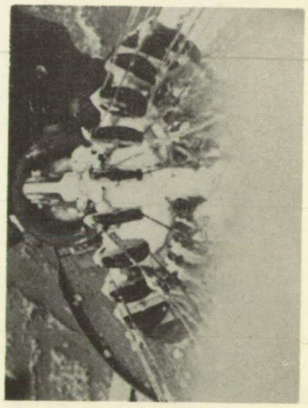


Camera - 11


Camera - 9



Camera - 8



Camera - 12

Figure 29.- Condition of the K-24 airship envelope, fins, and car after landing at 4:10 p. m., Mar. 22, 1945.

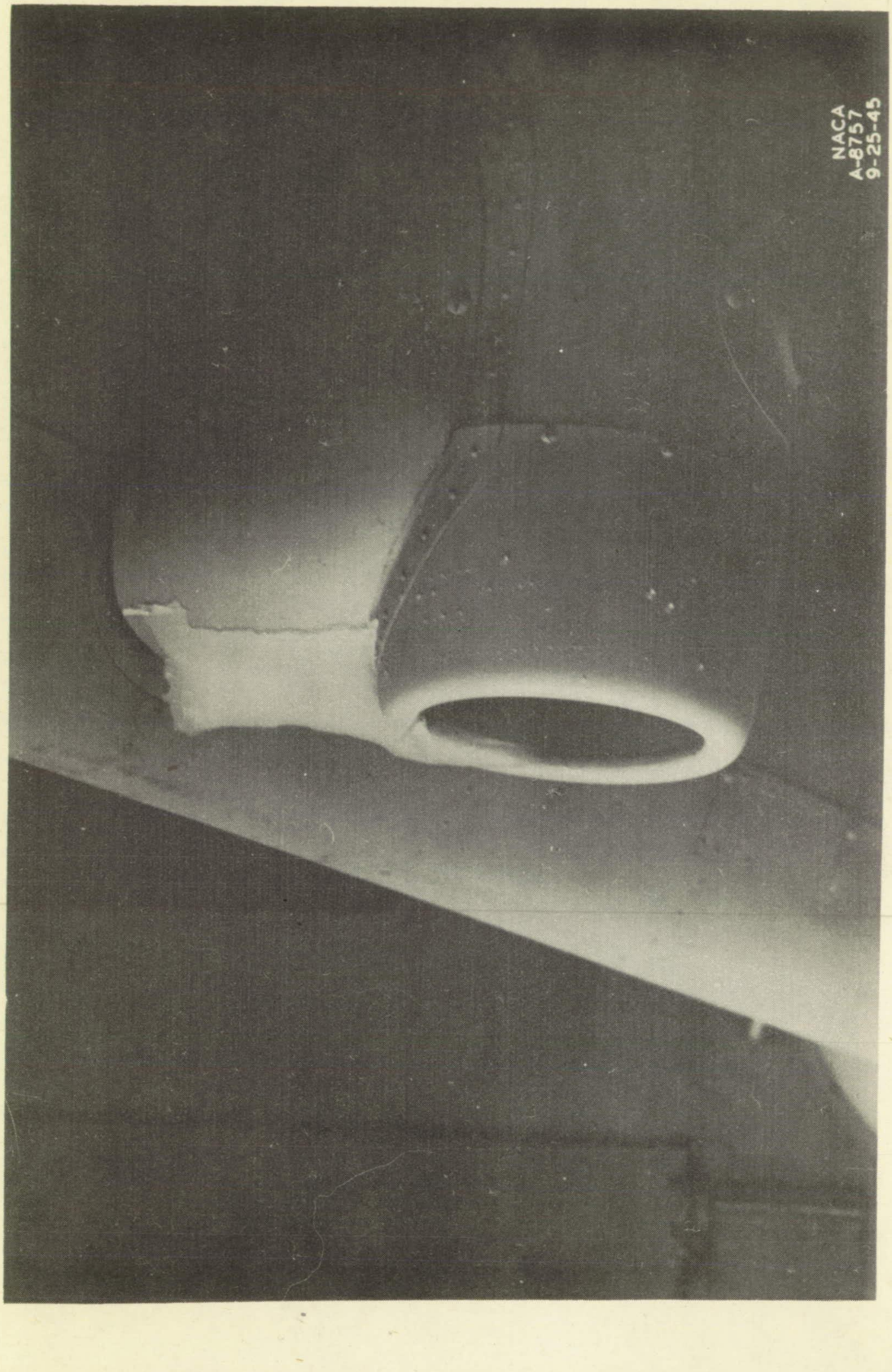



Figure 30.- Close-up of ice on the K-24 airship port oil-cooler strut after landing, Mar. 22, 1945.

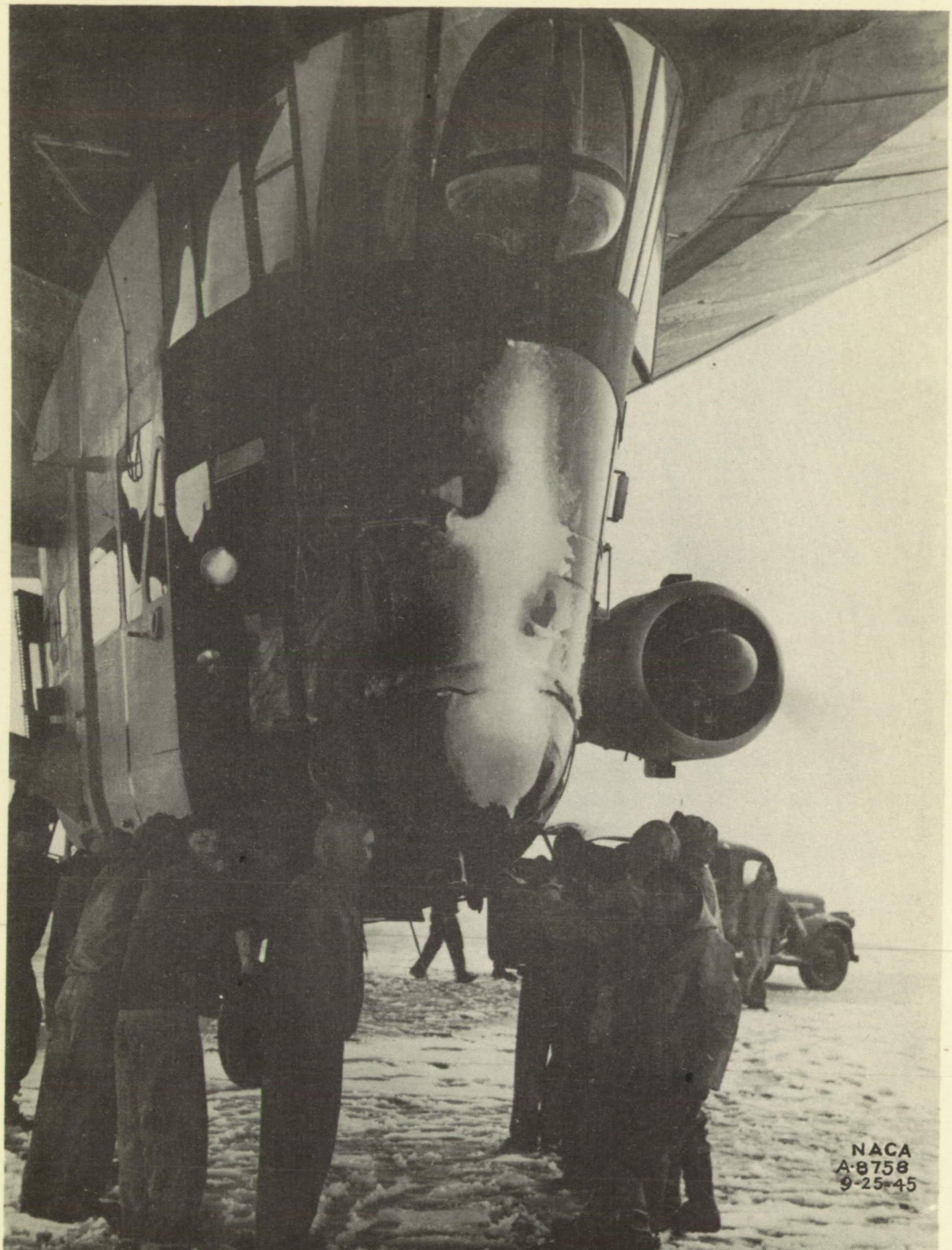



Figure 31.- Residual ice on the front of the K-24 airship car, spotlight, and humidity transmitter after landing, Mar. 22, 1945.

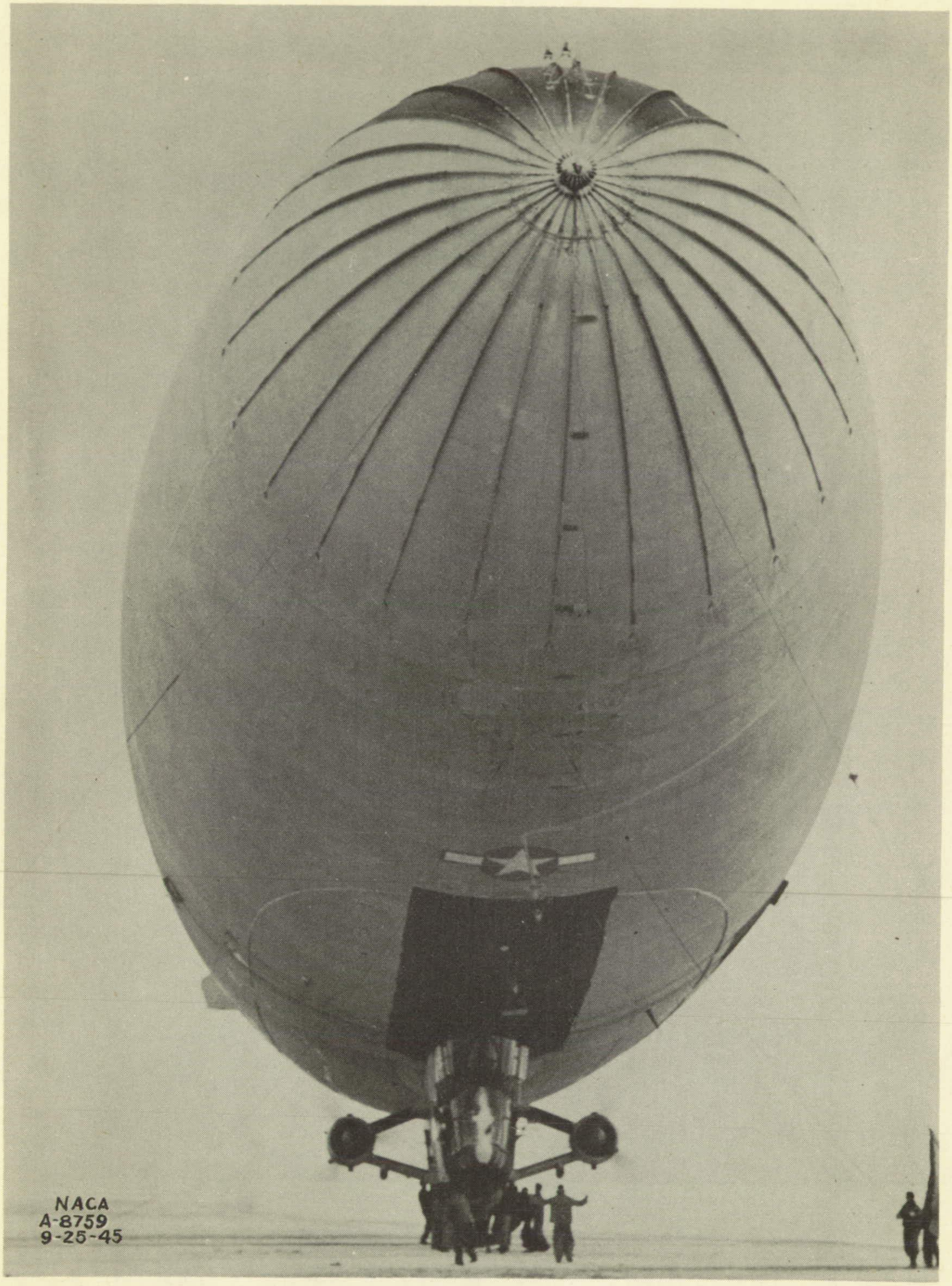



Figure 32.- Residual ice and snow on the bow of the K-24 airship after landing, Mar. 22, 1945.

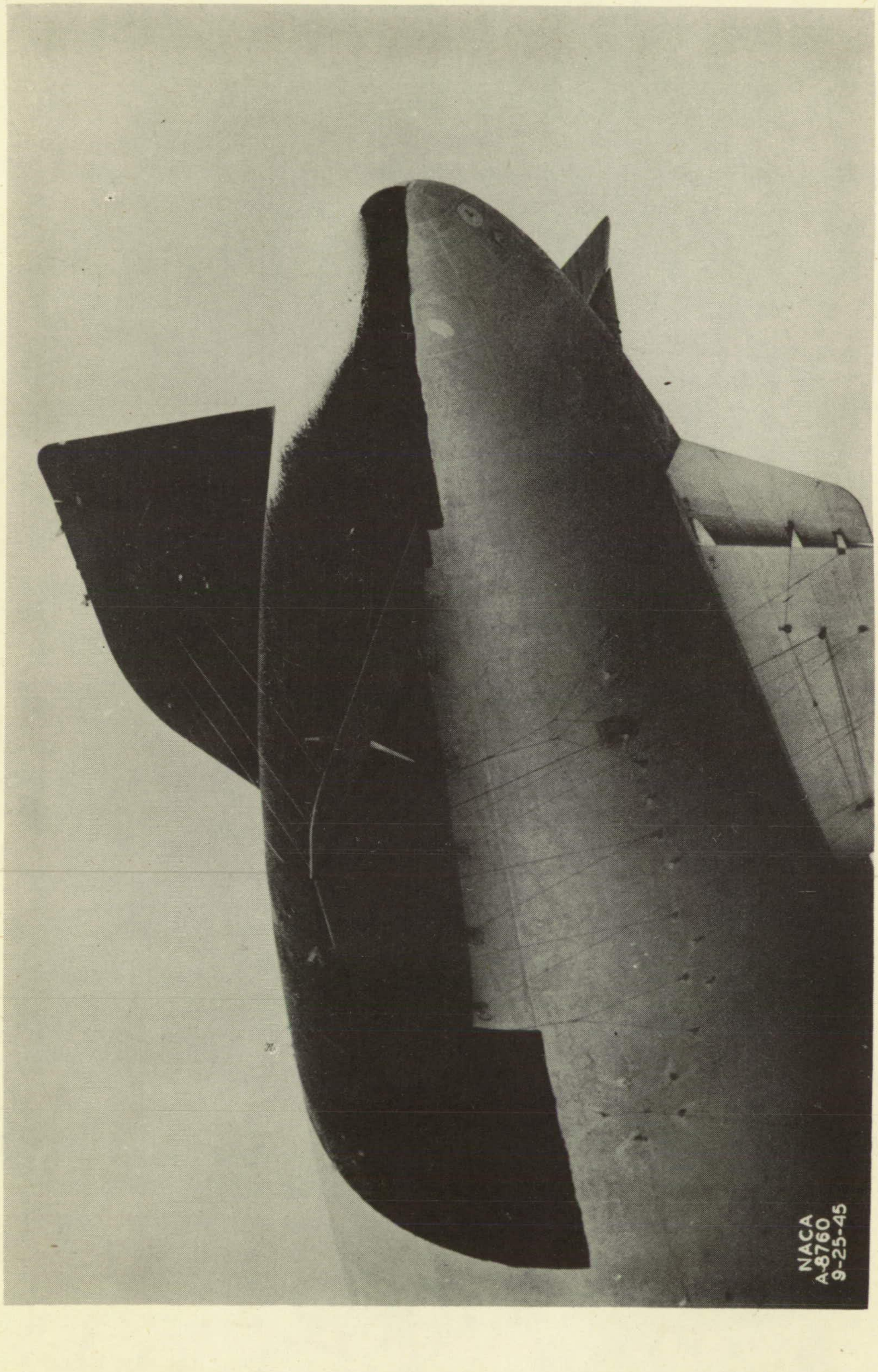



Figure 33.- Residual ice and snow on the stern of the K-24 airship after landing, Mar. 22, 1945.

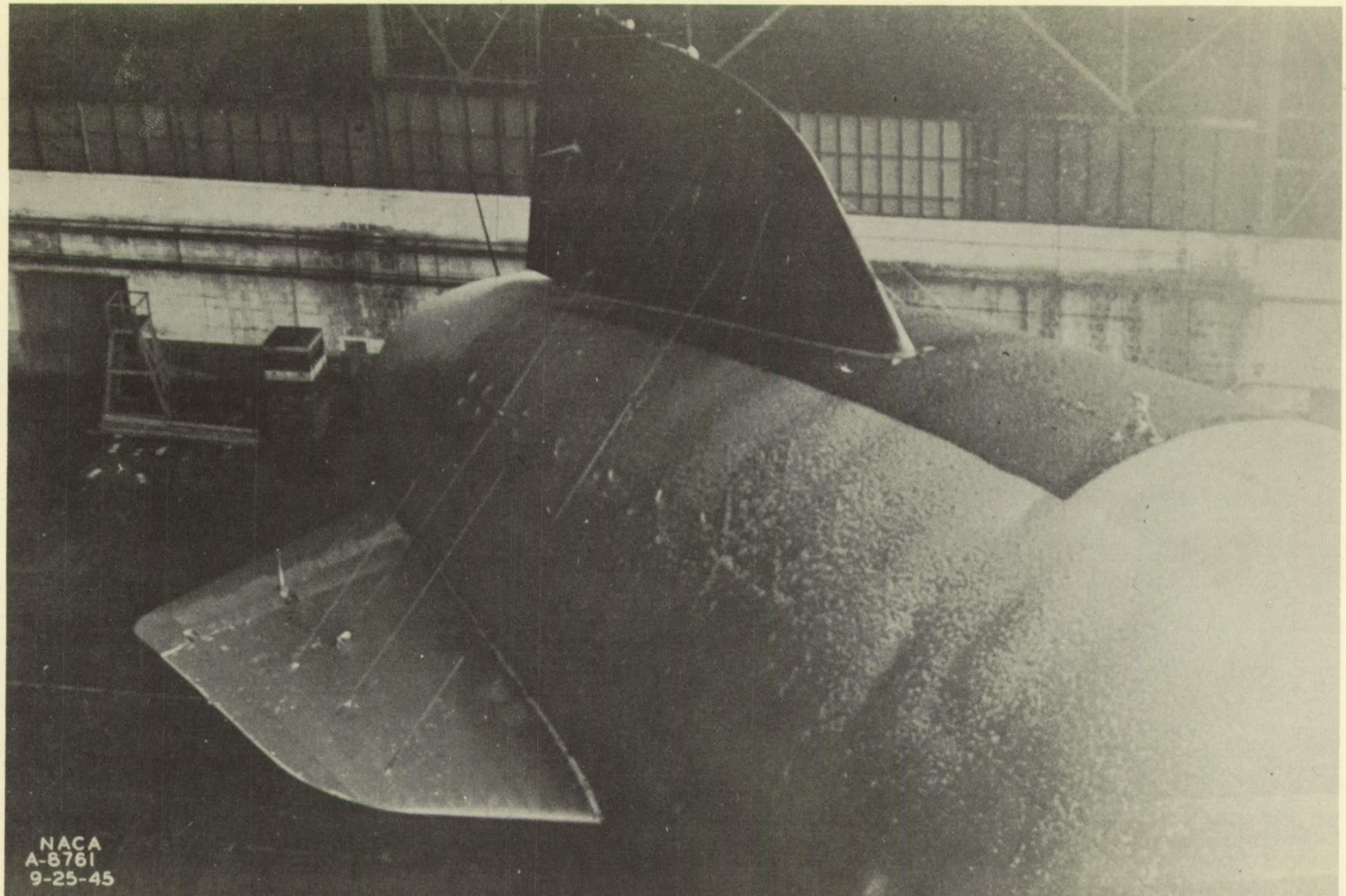



Figure 34.- Snow on the top of the K-24 airship envelope after landing, Mar. 22, 1945.

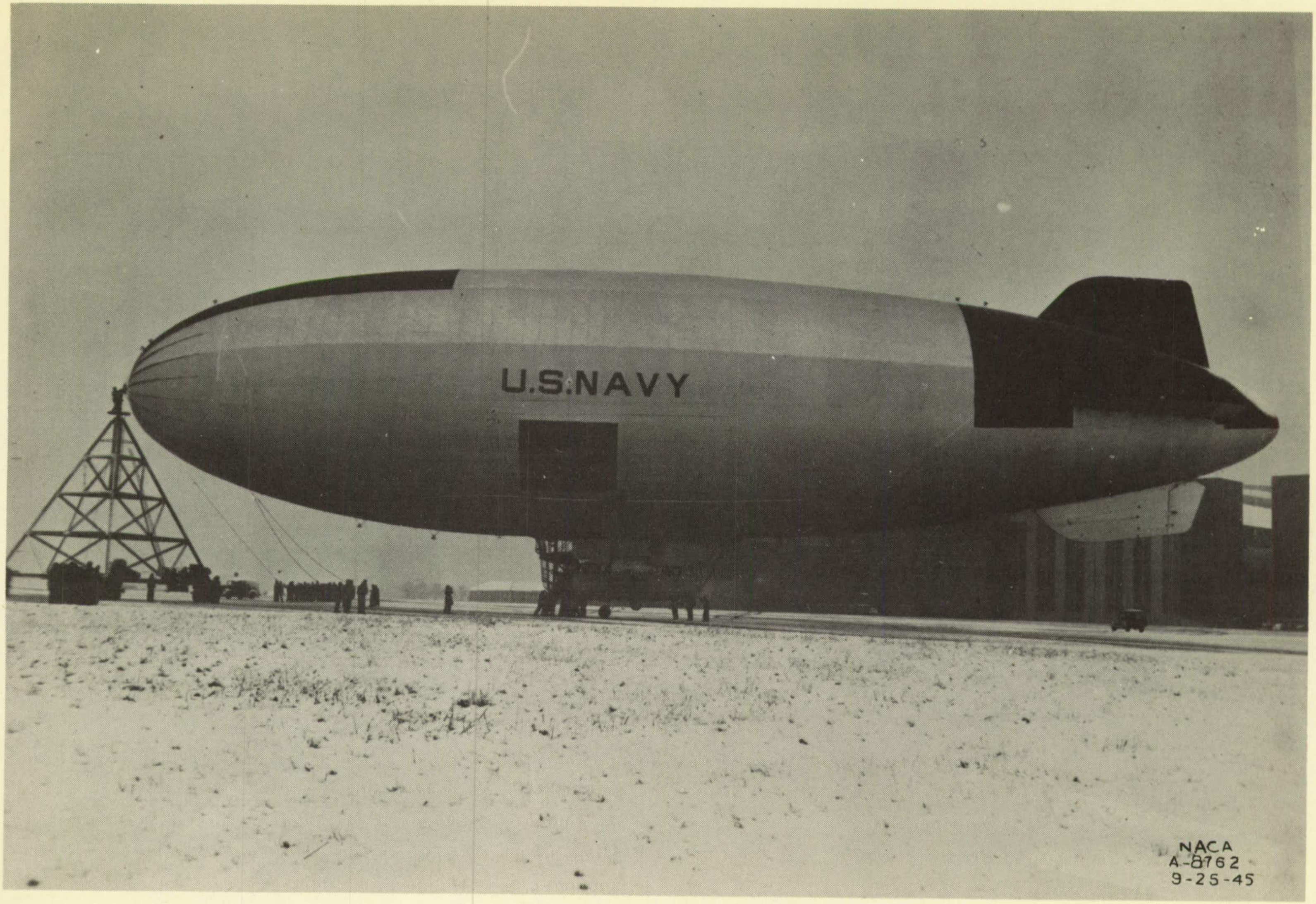



Figure 35.- The K-24 airship after landing, Mar. 22, 1945.

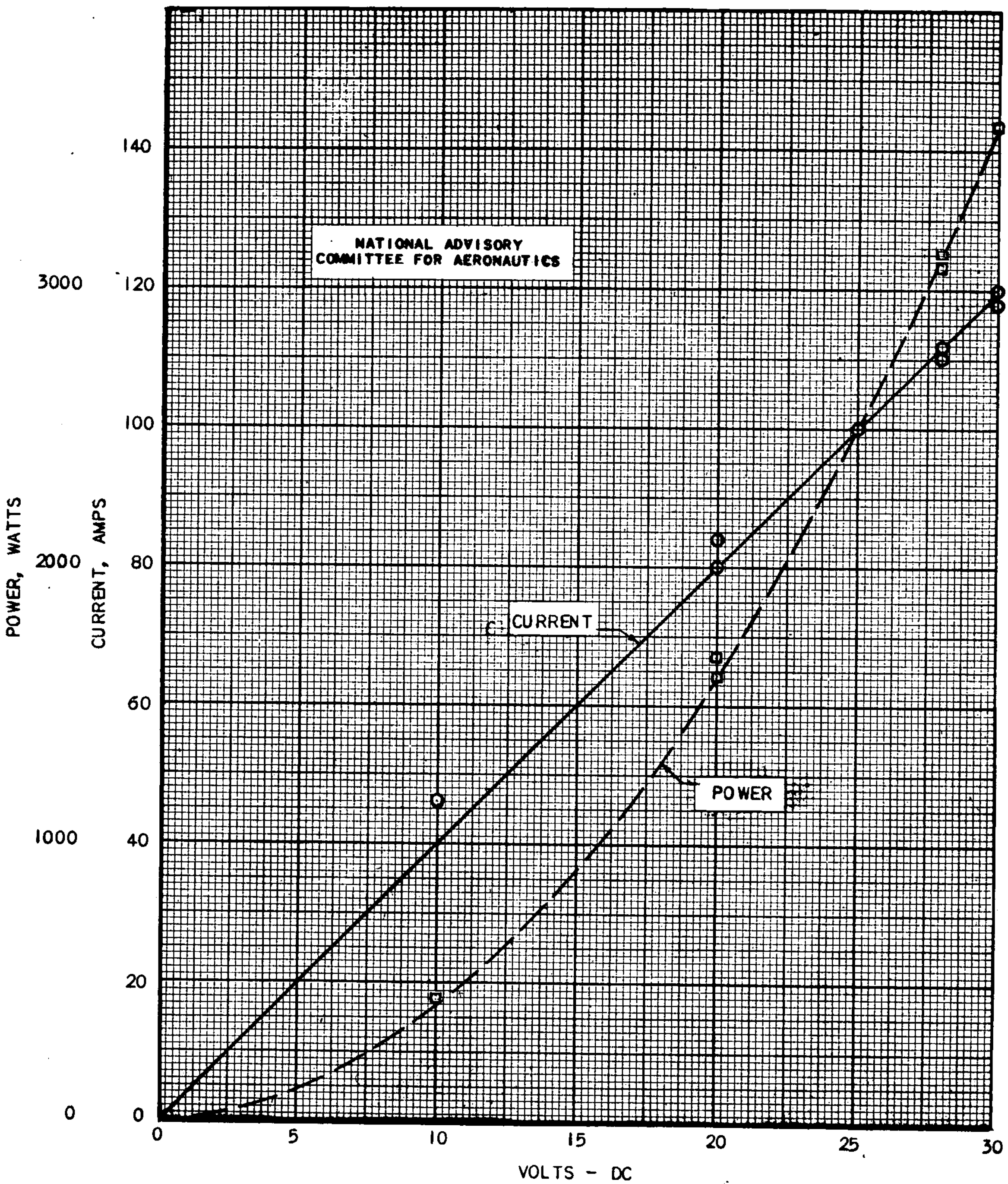



FIGURE 36. - TOTAL CURRENT AND POWER ABSORBED BY BLADE-SHOES ON EACH PROPELLER ON THE K-24 AIRSHIP.

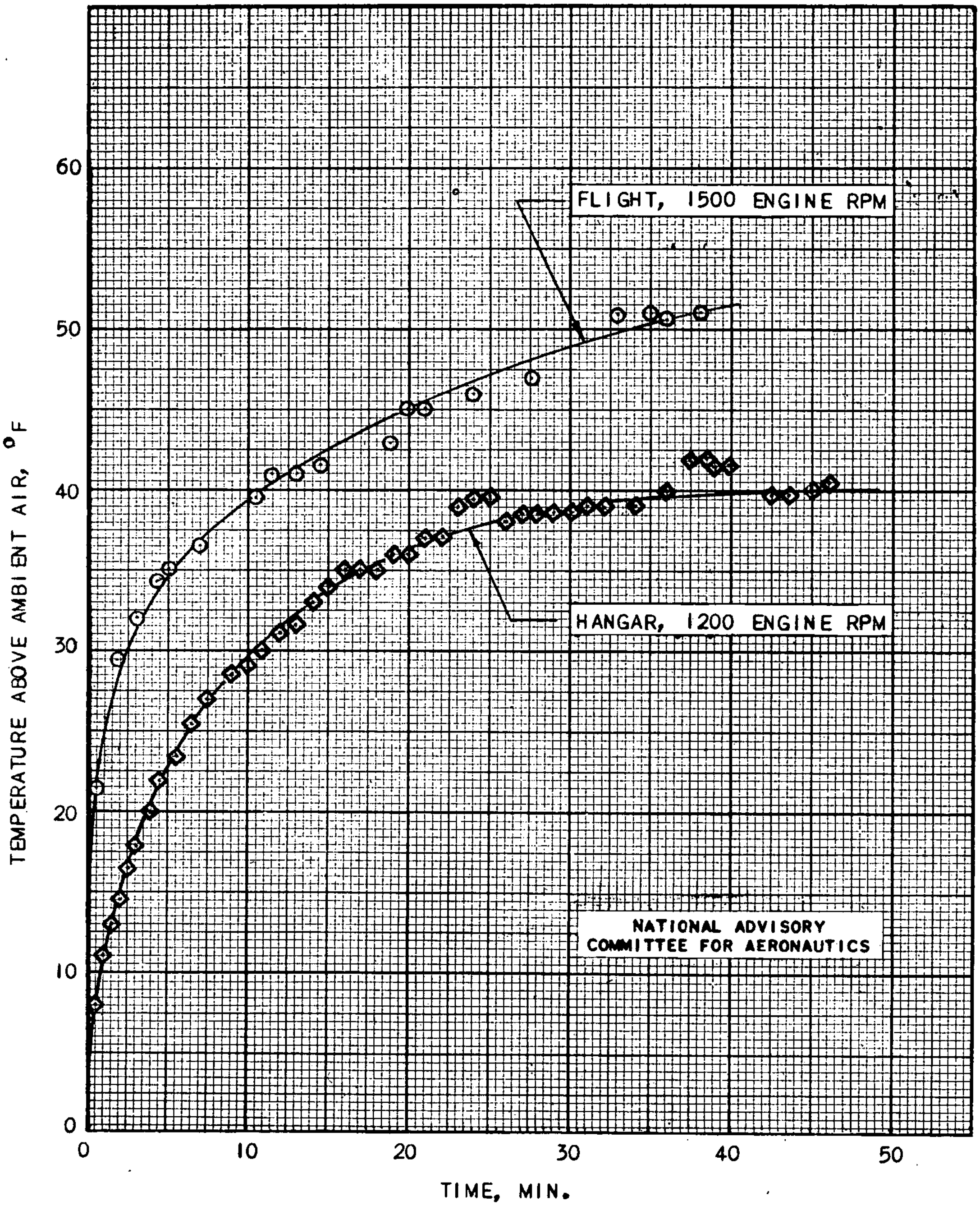



FIGURE 37. - TYPICAL PROPELLER TRANSIENT HEATING CURVES-BLADE-SHOES OPERATING AT 28 VOLTS.